Government of Nepal
Water and Energy Commission Secretariat
Singha Durbar, Kathmandu, Nepal

WATER RESOURCES OF NEPAL IN THE CONTEXT OF CLIMATE CHANGE

2011

Front cover picture: Mera Glacier
Back cover picture: Tso Rolpa Lake
Photo Courtesy: Mr. Om Ratna Bajracharya, Department of Hydrology and Meteorology, Ministry of Environment, Government of Nepal

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Water Resources of Nepal in the Context of Climate Change

2011

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Water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change.
“IPCC, 2007”

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Foreword

Climate change impacts are observed mainly in agriculture, forest, health and water resource in Nepal. Due to global warming and temperature rise at an annual rate 0.06°C over Nepal affects the water resource sector very heavily. The rise in temperature is more pronounced from southern zone to northern zone.

The water availability, quality and river discharge are very much sensitive to changing temperature and precipitation pattern. Water is considered to be major driver to climate change impacts. So, the climate change on water resource could directly affect agricultural productivity, human health, power generation and sanitation.

Water and Energy Commission Secretariat (WECS) is privileged to publish the document on Water Resource of Nepal in the Context of Climate Change with the assistance of WWF-Nepal.

Finally, I would like to appreciate the efforts and dedication made by Dr. Ravi Sharma Aryal; Joint Secretary and Mr. Gautam Rajkarnikar; Chief, Koshi River Basin Management Cell, WECS and Mr. Anil Manandhar and his team for their efforts in brining this document to this format.

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Acknowledgement

Water Resource of Nepal in the Context of Climate Change is an attempt to show impacts of climate change on one of the important sector of life, water resource. Water is considered to be a vehicle to climate change impacts and hence needs to be handled carefully and skillfully. The report is intended to present scenario of the impacts on water resource which is though challenging because water availability, quality of stream flow is sensitive to temperature and precipitation.

Climate change will affect everyone but developing countries will be hit hardest, soonest and have the least capacity to respond. South Asia is particularly more vulnerable to its impacts and some of the impacts already seen in Nepal in the form of drought, downstream flooding, intense rainfall, shifting of monsoon period. Nepal is suffering from either too much water or too little water to sustain life due to climate change.

Climate change impacts on water resource may be addressed by focusing on research, optimum observation network, strong database, adaptation and mitigation techniques. This report is an effort to bring some important issues of climate change to readers and building a strategy to cope with its impacts.

I would like to express my deepest appreciation and thanks to Mr. Gautam Rajkarnikar; Chief, Koshi River Basin Management Cell, WECS, who, as a key-person worked hard to bring out this publication. I would also like to express deepest appreciation and thanks to Consultants Mr. Adarsha Prasad Pokhrel and Prof. Dr. Narendra Man Shakya. Last but not least, I wished to express my heartfelt thanks to WWF-Nepal for their support in preparing this document.

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Acronyms

ADB	Asian Development Bank
APP	Agricultural Perspective Plan
BCM	Billion Cubic Meter
DHM	Department of Hydrology and Meteorology
DTW	Deep Tube Wells
ELA	Equilibrium Line Altitude
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture organization
GLOF	Glacial Lake Outburst Flood
ICID	International Commission on Irrigation and Drainage
ICIMOD	International Centre for Integrated Mountain Development
INPS	Integrated Nepal Power System
IPCC	Intergovernmental panel on Climate Change
km	Kilometer
LDOF	Landslide Dam Outburst Flood
MCM	Million Cubic million
MoFSC	Ministry of Forest and Soil Conservation
MoPE	Ministry of Population and Environment
MW	Megawatt
NEA	Nepal Electricity Authority
NENCID	Nepal National Committee ICID
OSE	Optimum Sediment Exclusion
PPA	Power Purchase Agreement
PPM	Parts Per Million
PTA	Power Trade Agreement
RoR	Run of River
SPOT	Satellite Pour Observation de la Terre
Sq km	Square Kilometer
STW	Shallow Tube Wells
UNEP	United Nations Environment Program
VDC	Village Development Committee
WECS	Water and Energy Commission Secretariat
WMO	World Meteorological Organization
WUA	Water User's Association

Executive Summary

1 Climate change impacts are observed in several sectors of Nepal among which water resources is one of the hardest hit sector. Evaluating the impacts in water resources is challenging because water availability, quality and stream flow are sensitive to changes in temperature and precipitation. Increased demand for water caused by population growth, changes in the economy, development of new technologies, changes in watershed characteristics and water management decisions are some of the other factors to be taken into consideration. Water is considered to be a vehicle to climate change impacts and hence needs to be handled carefully and skillfully.

2 Nepal is rich in water resources. There are about 6000 rivers in Nepal having drainage area of 191000 sq. km, 74 % of which lies in Nepal alone. There are 33 rivers having their drainage areas exceeding 1000 sq. km. Drainage density expressing the closeness of spacing of channels is about 0.3 km/sq. km. If this natural resource is properly harnessed, it could generate hydropower; provide water for irrigation, industrial uses and supply water for domestic purposes.

3 Rivers of Nepal can be broadly classified into three types, in accordance to their origins: The first category comprises of the four main river systems of the country: Koshi, Gandaki, Karnali and Mahakali river systems, all of them originating from glaciers and snow-fed lakes. Rivers of the second category originate from Mahabharat range which includes Babai, West Rapti, Bagmati, Kamala, Kankai and Mechi etc. Streams and rivulets originating mostly from the Chure hills make up the third category; these rivers cause flash floods during monsoon rains and remain without any flow or very little flow during the dry season.

4 Currently, about 10% of total precipitation in Nepal falls as snow, about 23% of Nepal's total area lie above the permanent snowline of 5000 m., about 3.6% of Nepal's total areas are covered by glaciers. There are 3,252 glaciers covering an area of 5,323 sq.km with an estimated ice reserve of 481 km^3. There are 2323 glacial lakes in Nepal covering an area of 75 sq.km.

5 The surface water available in the country is estimated to be about 225 billion m^3 (BCM) per annum or equivalent to an average flow of 7,125 m^3/s, out of which only 15 BCM per annum is in use. Around 95.9% of 15 BCM has been used for agriculture, 3.8% for domestic purpose and only about 0.3% for industry. It is observed that around 78% of the average flow of the country is available in the first category river basins, 9 % in the second category basins and 13 % in the numerous small southern rivers of the Terai. Studies have shown that the first Category Rivers have surplus flow but the second category rivers have deficit flow in the dry season.

6 Nepal's economy is largely based on agriculture; it contributes about 40% to GDP and provides employment to two-thirds of the population. However, Nepalese agriculture is mainly rain fed and agriculture production in both rain fed as well as irrigated areas are being badly affected due to droughts, flooding, erratic rainfall, and other extreme weather events. Nepal was self sufficient in food grain production until 1990. Due to drought condition in 2005/06, production fell short by 21553 metric tonnes and by 179910 metric tonnes in 2006/07 due to drought and natural calamities.

7 Nepal has a cultivated area of 2,642,000 ha (18% of its land area), of which two third (1,766,000 ha) is potentially irrigable. At present 42% of the cultivated area has irrigation of some sort, but only 17% of cultivated area has year round irrigation. An estimate shows that less than 8% of the country's water potential is used for irrigation.

8 In addition to surface water, a large volume of water is available in the shallow and deep aquifers which are estimated to be 8.8 BCM annually which can be used for irrigation and domestic water supplies.

9 The estimated hydropower potential of Nepal is 83,000 MW of which 114 projects having 45,610 MW have been identified economically feasible. However in the context of climate change the hydropower development scenario needs to be revisited in totality. At present, Nepal Electricity Authority (NEA) has a total installed electricity generation capacity of about 689 MW, of which the hydropower capacity is 632 MW.

10 Only about 72% of the country's population has access to basic water supply and only 25% of the whole population has sanitation facility.

11 Nepal is highly vulnerable to recurrent floods and landslides. In Nepal, devastating floods are triggered by different mechanisms such as: i) continuous rainfall and cloudburst (CLOFs), ii) glacial lake outburst floods (GLOFs), iii) landslide dam outburst floods (LDOFs), iv) floods triggered by the failure of infrastructure, and v) sheet flooding or inundation in lowland areas due to an obstruction imposed against the flow.

12 According to the precipitation trend analysis, the annual average precipitation over Nepal is decreasing at the rate of 9.8 mm/decade, however the Koshi basin shows increasing trend. Trend of the annual discharge of three major River basins Koshi, Gandaki and Karnali indicates that the discharges in these major basins are decreasing annually but, the annual discharges in southern basins were in increasing trend.

13 Analyses of monthly flow trend of some of the rivers indicate that the contribution of snow melt in runoff is in increasing trend for snow-fed rivers, similarly for non snow-fed rivers, dry season flows are decreasing and wet season flows are increasing. It is also observed that the numbers of flood events are increasing as well as the effect of single flood is also increasing to more days. The changing precipitation pattern indicated that the drought period was becoming longer, though there was no definite trend in the annual precipitation amount.

14 The impact on snow and glacier is found to be very high. Negative trends are observed in the glacier mass balance. Glacial Lakes are expanding and the threats of Glacial lake Outburst Floods (GLOF) are ever increasing.

15 Agriculture is the mainstay of Nepal's economy. Climate variability directly affects agricultural production, as agriculture is one of the most vulnerable sectors to the risks and impacts of global climate change and water shortages. Any further decreases in water resources, especially during the non-monsoon seasons, would adversely affect agricultural production. It will have a direct impact on the livelihood of the people.

16 Climate change impacts on water resources may be addressed by focusing on i) Research, ii) Optimum observation network, iii) Strong data-base and, iv) research based action oriented program/projects. In general they are: establishment of a strong water-resources data base including snow and glacier information. Integrated river basin study, pilot river basin study demonstration projects, development of suitable climate models, establishment of a model test laboratory, redefinition of the water structure design criteria and identification of vulnerable areas and climate friendly technologies, development of adaptive measures and proper implementation, research on water resources to apply 3R (reduce, reuse and recycle) principle as well as study on addressing the climate change impacts on landslides, debris flow, floods and droughts are also necessary to cope with the climate change. Creation of mass awareness, formation of climate change sectoral policies on water resources relation matters, stringent judicial enforcement, reliable information on the Himalayan snow and glacier field, capable human resources development, creation of opportunities for higher studies are some other necessary things to be planned and carried out in a proper and effective ways.

17 Water and Energy Commission Secretariat (WECS) has to take the supervisory role in collection, compilation, processing and maintaining a strong data base and has to take a lead role in conducting the above activities.

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The Context of Climate Change

1. Introduction

Water is indispensible for life. But, 97.5% of all the water on Earth is saltwater, leaving only the remaining 2.5% as freshwater. Approximately 70% of the freshwater available on the planet is frozen in the icecaps of Antarctica and Greenland. This leaves only the remaining 0.7% of the total water resources worldwide accessible for direct human uses. This is the water found in lakes, rivers, reservoirs and those underground sources that are shallow enough to be tapped at an affordable cost. This also is the only amount that is regularly renewed by rain and snowfall and therefore available on a sustainable basis.

Freshwater is mainly utilized for household use, water supply, agriculture and in industries. About 67% of the water is used in irrigation for the production of food grains worldwide. The per capita use of water also reflects the living standard and economic activities of the people. The comprehensive assessment of water management in agriculture revealed that one in three people are already facing water shortages (IPCC, 2007). Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage (where countries lack the necessary infrastructure to take water from rivers and aquifers); nearly all of which are in the developing countries. To make it worse, while resources are limited, the demand of water in such countries is ever increasing with the growth in population.

Furthermore, the spatial and temporal distributions of freshwater are highly sensitive to climate change resulting in a more unfavorable situation. These impacts are more prominent in a mountainous country like Nepal. The dense orographic barriers and substantial snow and glacier covered areas are mainly accountable for such responses affecting the planning, development and management of water resources of the country.

2. Status of Water Resources in Nepal

Nepal is endowed with abundant water resources from an availability point of view. The bodies of water here are regarded as the key strategic natural resources with the potential to act as the catalyst for the all-round development and economic growth of the country. There are about 6000 rivers in Nepal with a total drainage area of 194,471 sq. km. Out of this, 74 % lies within the country. 33 of these rivers have a drainage area that exceeds 1000 sq. km. The drainage density expressing the closeness of the spacing of channels is about 0.3 km/sq. km. The development of Nepal's water resources could generate hydroelectric power, furnish water for irrigation and supply water for domestic and industrial uses.

2.1 River Systems in Nepal

Depending on their source and discharge, the rivers in Nepal can be classified into three types. The Mahakali, Karnali, Gandaki and the Koshi are the four main river systems. They originate in the Himalaya and carry snowfed flows with significant discharge even in the dry season. These rivers are perennial and have tremendous potential as a source of irrigation and hydropower development. The Babai, West Rapti, Bagmati, Kamala, Kankai and the Mechi are medium rivers. These rivers originate in the Midlands or the Mahabharat Range and are fed by precipitation as well as groundwater regeneration (including springs). These rivers too are perennial but are commonly characterized by a wide seasonal fluctuation in discharge. In addition to these large and medium river systems, there are a large number of

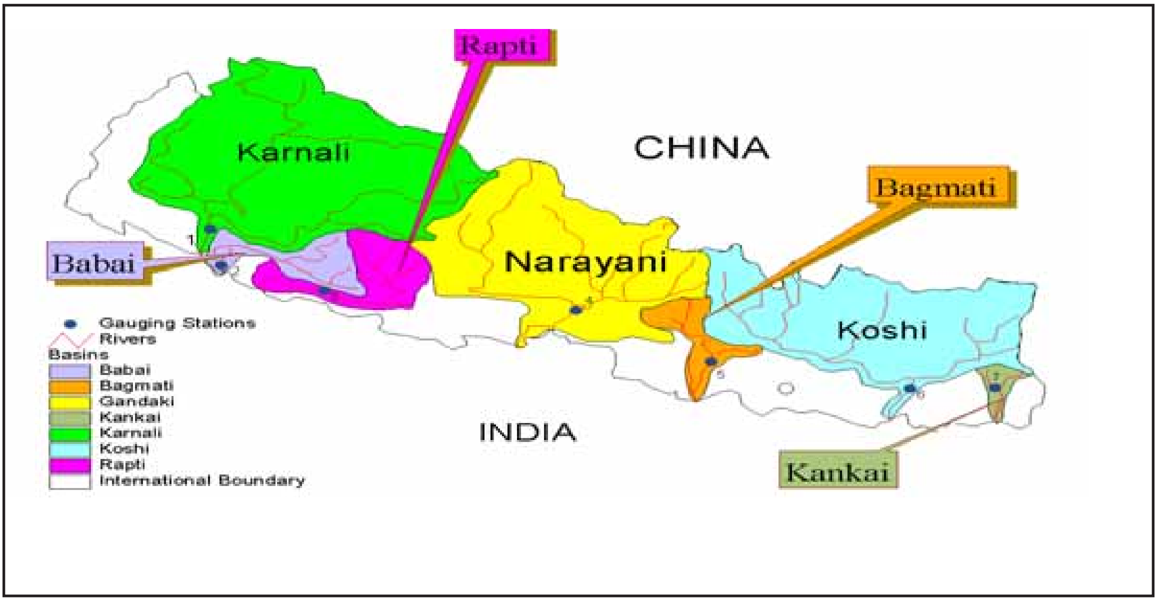


Figure 1: The river basins in Nepal (Prepared by: A Pokhrel and N.M. Shakya. 2010)

small rivers in the Terai which mostly originate in the Siwalik Range. These rivers are seasonal with little flow during the dry season which renders them unsuitable for year-round irrigation or hydropower generation without surface storage.

The rivers in Nepal are characterized by wide, seasonal fluctuation of flow. The monthly flows generally reach their maximum in July-August and decline to their minimum in February-March. About 80% of the total flow occurs during five months (June - October) and the rest during the remaining months. It can be generalized that the smaller the size of the river catchment area, the wider is the range of flow fluctuation.

2.2 Physiographic and Climatic Characteristics of Nepal

The temporal and spatial variations of river flows are mainly due to the physiographic and climatic characteristics of the country resulting in time and space distribution of rainfall. Although Nepal lies near the northern limit of the tropics, there is a very wide range of climate - from the summer tropical heat and humidity of the Terai to the colder, dry continental and alpine winter climate through the middle and the northern mountainous sections. The amount of precipitation and the range of temperature vary considerably because of the exceptionally rugged terrain.

Nepal has two rainy seasons. The more prominent of the two lasts from June to September when the south-west monsoon brings about 80% of the total rainfall. The other, which accounts for 20% of the total annual rainfall, occurs during the winter. The eastern part of the country experiences more rain than the western part. The downpour is maximum in the hilly regions of the central part of the country. It is particularly so at the southern flanks of the Annapurna Range and goes on decreasing both on the northern and southern sides. This is mainly due to the highly spatially varying topography resulting in varying orographic effects in the country. Beside, pre-monsoon thunderstorms occur from March onwards as a result of the increasing temperature in the sub-continent (Sharma CK, 1977). They are usually strongest in the Terai but can also be spectacular in the hills. They give appreciable amounts of rain in short periods and can ease the drought - temporarily - at the hottest time of the year.

In both spring and autumn, Nepal can be affected by the tail of cyclones generated over the Indian Ocean and which reach the country through the Bay of Bengal. These can give several days of heavy rain. The other pre- and post-monsoon rains occur during unsettled climatic conditions just before and after the monsoon. In some years, they serve to extend the wet period by a month or more.The mean annual precipitation ranges from more than 6,000 mm along the southern slopes of the Annapurna Range in central Nepal to less than 250 mm in the north-central portion near the Tibetan plateau (WECS, 2000). Amounts varying between 1500 and 2500 mm predominate over most of the country. The distinct maxima are reached along the southern slopes of the Mahabharat Range and the Himalayan

Ranges in the eastern two-third of the country. The minima stretch east-west through the mid-section of the country. On an average, about 80% of the precipitation is confined to the monsoon period (June - September).

The spring months are characterized by windy weather, increasingly higher humidity and pre-monsoon thunderstorms. Snowfall is confined to the northern and western mountainous regions, especially at elevations above 3,500 meters. The maximum temperature during the summer and late spring - May being the warmest month - ranges from more than 40^0c in the Terai to about 28^0c in the mid-section of the country. Much colder temperature prevails at higher elevations.

These dynamic and statistical features of both the weather and the terrain are reflected in the river hydrology. Features like the flow in the river, size of the channel, gradient and the sediment load are all governed by the intensity of rainfall, topography and the type of rocks. On this basis, the rivers in Nepal are classified into the perennial rivers of the mountains and the seasonal rivers of the Terai.

2.3 Distinction of Hydrologic Zones

The spatial variation in the climatic and terrain features is very high in Nepal. This has resulted in several distinct zones in terms of the hydrologic response of the catchments. Nepal's topography is inclined southwards towards the Ganges River. All the four major river systems predate the uplift of the main Himalayan Ranges and have kept pace with the uplift so that they now cut through the ranges in deep valleys. In the mountain and midland zones, the geology tends to promote rapid run-off resulting in a dense network of small, steep streams draining into the major rivers. In contrast, the geology promotes groundwater storage in the Siwalik Hills, on the Terai margins and the inner Terai.

The run-off is concentrated in the monsoon season. The contribution of snowmelt to the total run-off occurs mainly from March to July. In catchments below 3000 m, there is no significant contribution from snow.

Based on the climatic features and the responses of the basins, seven hydrological zones are identified in Nepal (WECS/DHMN, 1996). They are:

1 Mountain Catchments,

2 Hills to the north of the Mahabharat Range, rivers rising north of the Siwaliks, the inner Terai,

3 Pokhara, Nuwakot, Kathmandu, the Sun Koshi tributaries,

4 Lower Tamur Valley,

5 River draining the Mahabharat Range,

6 Kankai Mai Basin; and

7 Rivers draining from the Churia Range to the Terai.

On the basis of their morphological and sediment characteristics, the rivers in Nepal can further be classified into the following groups:

Antecedent rivers:

The river valleys are narrow and deep in the higher Himalayan Ranges. The exceptions are those in the glacial areas where they mostly are U-shaped; waterfalls, cascades and rapids are very common; and the landscape is dotted with numerous glacial lakes and pools. The erosive power of the river is high. The banks cutting is common and meandering is limited.

The moment a river enters the midlands, the east-west course is nearly level; the gradient is poor; and the velocity is low. River meandering is common. Terrace deposits are found in this zone. While cutting the midlands and the Churia Hills, the gradient and the erosive power are again high and the valleys become narrow. In the Terai plains, the river dumps its load at the point of emergence from the Churia Hills; the same river makes two-three channels and flows in different channels at different times. On reaching the mid - Terai, it again starts meandering. Here, oxbow lakes and changes in the river courses are common.

Mahabharat rivers:

The rivers originating from the northern face of the Mahabharat mostly have a north-south flow; the gradient is high; and the valleys are deep and narrow. However, in the southern face, they mostly have an east-west flow parallel to the Churia Hills and finally cut at some point to emerge out. The behavior of such rivers is the same as that of the antecedent rivers. In the Terai, the northern channels are flat but become narrow and deep on reaching the Indo-Nepal border.

Churia Hill rivers:

The rivers at the northern face join with the Mahabharat rivers and are steep and straight. But, those at the southern face rarely follow an east-west course but go straight to the Terai instead. The river valleys are comparatively flat.

Terai rivers:

These rivers mostly originate from the spring line of the Terai. They follow a fairly straight path (with some meanderings) and join either with the Mahabharat or the Churia rivers near orat the Indo-Nepal border. The river valleys are comparatively deep.

In the mountains, the general gradient of the rivers is about 40 m per km. However, due the hardness of the rocks here, it becomes very difficult for the rivers to make heavy cutting in most of the places. In the north-south course of the main river, narrow and wide valleys occur in an alternating fashion where hard rocks and soft rocks are inter-bedded.

The river makes a narrow valley in the hard rock. But, the moment it meets soft rock like phyllite, wide valley cutting is found. Sedimentation is observed in the wide valleys on the floodplains. When the river is confined to the two walls of a narrow valley, it starts scouring the bed heavily. The moment it comes out into the midlands with valleys stretching wide, its velocity is reduced.

In the midlands, both due to the rocks being soft and deforestation by a heavy population, the fine debris and coarse sand from the landslide and gully erosion processes are added. Fortunately, a river in the east-west direction has a lower gradient and the sediment -carrying capacity is limited. As a result, in the case of the major rivers, by the time they reach the Terai plains, the sediment consists of mainly sand and silt. But, the rivers originating in the Mahabharat and Churia Hills - which flow only a few kilometers before they reach the Terai - are capable of transporting sediments of the order of one meter in size.

All the rivers in the Eastern Terai bring heavy amounts of sand during the floods which cover the entire area. The rivers take a different course in the next flood and the meandering starts. Most of the rivers in Eastern Nepal have sand deposits in the river channel and the bed has risen up to the adjoining land surface. The classic examples of such rivers are the Biring, Bakra and the Ratu in the east, the Manahari and Lothar in the middle, the Tinau in the west and the Dondra in the far-west.

The hydrological behavior of the rivers originating in the Siwaliks and also that of the other rivers after crossing this range is very special. It is due to the presence of a highly pervious debris deposit at the Bhabar Zone which lies between the Churia and the Terai plains. The mean monthly discharges of the Bagmati River at Padherodovan and Karmaiya show apparently less discharge during the dry season, despite its larger catchment area as compared to the former. This observation is mainly the result of the highly permeable riverbed in the Bhabar Zone. This indicates the need for adequate numbers of gauging stations in both the Bhabar and the Terai plains. However, there are no gauging stations either at the Terai rivers or the rivers originating in the Siwalik Range. The knowledge of the temporal variationin the flow of these rivers is important for the planning of water resources development.

Snow and Glaciers

The hydrological responses of the snow-covered and glaciated areas are distinct from the other zones. About 23% of Nepal's total area lies above the permanent snowline of 5000m (MoPE, 2004). Presently, about 3.6% of Nepal's total area is covered by glaciers (Mool P. et al., 2001). About 10% of the total precipitation in Nepal falls as snow (UNEP, 2001).

A study on the glaciers in the Nepal Himalaya (Mool P. et al., 2001) divided the area into four major river basins from east to west. It revealed 3,252 glaciers with a coverage area of 5,323 sq. km and an estimated ice reserve of 481 km^3. According to this study, the Koshi River Basin comprises 779 glaciers with an area of 1,409.84 sq. km and an estimated ice reserve of 152.06 km^3. There are altogether 1,025 glaciers in the Gandaki River Basin which cover an area of 2,030.15 sq. km and the basin has an estimated ice reserve of 191.39 km^3. The Karnali River Basin consists of 1,361 glaciers with an area of 1,740.22 sq. km and an estimated ice reserve of 127.72 km^3. Only 35% of the Mahakali River Basin, comprising 87 glaciers, lies within Nepali territory. The area covered by these glaciers is 143.23 sq. km and the estimated ice reserve is 10.06 km^3.

All the lakes at elevations higher than 3,500 masl are considered to be glacial lakes (Mool P. et al., 2001). Some of the lakes are isolated and far behind the ice mass. Their inventory of glacial lakes revealed 2,323 lakes with coverage of 75 sq. km in Nepal. The Koshi River Basin contains 1,062 lakes, the Gandaki River Basin 338 lakes, the Karnali River Basin 907 lakes and the Mahakali River Basin (within Nepali territory) contains 16 lakes.

2.4. Quantitative Summary of the Water Resources of Nepal

The surface water available in the country is estimated to be about 225 billion m3 per annum, equivalent to an average flow of 7,125 m3/s (WECS, 2003). The total drainage area of these rivers is around 194,471 km2, 76% of which lies within Nepal.

S.N.	River	Length (km)	Drainage Area (km2)		Estimated Runoff (m3/sec)	
			Total	Nepal	From all Basins	From Nepal
1	Mahakali	223	15,260	5,410	698	247
2	Karnali	507	44,000	41,890	1441	1371
3	Babai	190	3,400	3400	103	103
4	West Rapti	257	6,500	6,500	224	224
5	Narayani	332	34,960	28090	1753	1409
6	Bagmati	163	3,700	3,700	178	178
7	Sapta Koshi	513	60,400	31940	1658	878
8	Kankai	108	1330	1330	68	68
9	Other River		24921	24921	1001	1001
Total			194,471	147,181	7125	5479

Table 1: Estimated runoff from the rivers of Nepal (WECS, 2003)

S.N.	Description	Unit	Estimated Values	
			For all Basins	For Nepal
1	Mean Specific Runoff	$m^3/sec/km^2$	0.0366	0.0372
2	Annual Runoff	million m^3	225000	173000
3	Average Annual Precipitation	mm/year	N/A	1530
4	Mean Runoff Coefficient	-	N/A	0.768

Table 2: Estimated summary of runoff statistics (WECS, 2003)

The variation in the availability of water resources in terms of time and space are very much different. To make it even worse, the water demand for domestic, industrial, irrigation, hydropower generation, environmental requirements etc. do not necessarily match temporally and/or spatially with the available water supply.

It is seen that around 78% of the average flow in the country is available in the four major basins, 9 % in the medium basins and 13 % in the numerous small southern rivers of the Terai. As the southern slopes of the Mahabharat Range, the Himalayan Range and the eastern two-third of the country receive the maximum precipitation, there is more contribution from the flow of these catchments. About 74 % of the total annual surface flow occurs in the four months of June - September. The 42% of the population resides in the major basins, 18% in the medium and 40% in the Terai region covered by the southern rivers. Irrigation demand is major conjunctive use in a basin. As illustrated in Figure 2, the basin-wise distribution of population and water availability has resulted in some basins having excessively surplus water availability and some basins with deficit water availability. This renders the planning and management of water resources an additionally complex task.

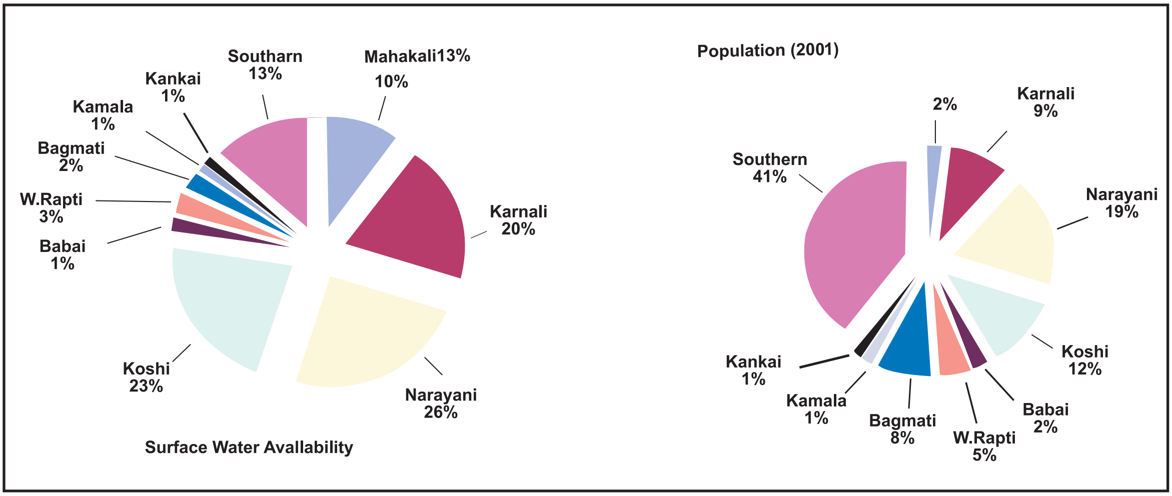


Figure 2: Distribution of water availability and population in the various basins of Nepal (WECS, 2003)

The glaciers in the High Himalayan region of Nepal are very important features that sustain water availability in the region. It is particularly so during the lean flow seasons when the melt-water contribution is crucial for the supporting of human activities and ecosystem services in both these areas and downstream. The glaciers in the nine basins (as shown in Figure 3) contain approximately 70% of the total glacier surface area in the Nepal Himalaya. The glacier contribution to the total stream flow of the basins in which they are situated varies widely among basins - from approximately 30% in the Budhi Gandaki basin to approximately 2% in the Likhu Khola Basin.

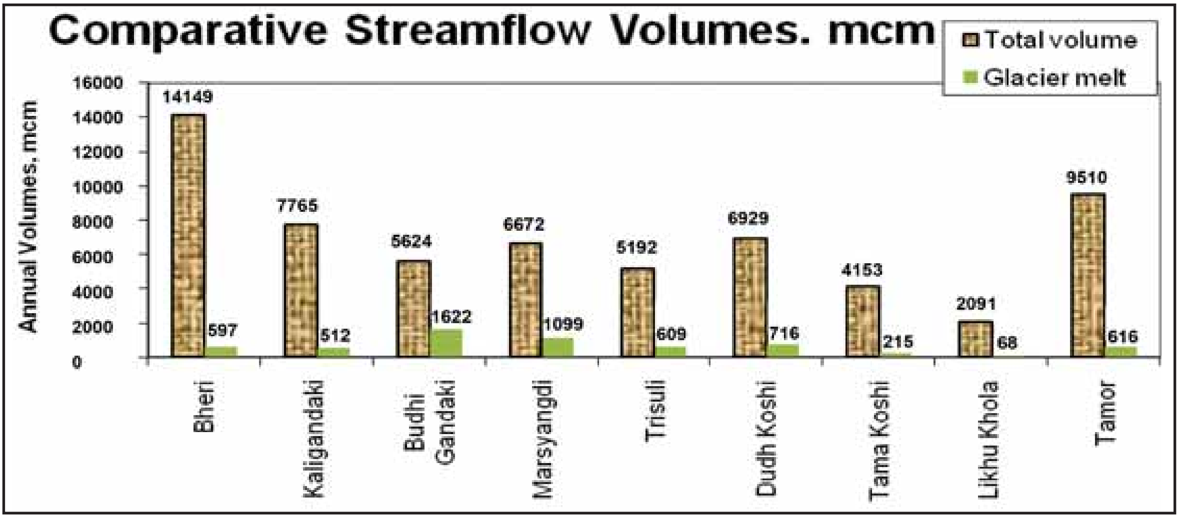


Figure 3: A graph, showing the relative annual streamflow, in million cubic meters, mcm/yr (World Bank, 2009)

The water balance of the main river basins is presented in Figures 4 and 5. It can be seen that during the dry season, the major basins have surplus flow but the medium basins have deficit flow. Water balance is, however, very dynamic and sensitive to climate change and its trends.

The basic observed information for such analysis is the hydro-meteorological dataset maintained by the Department of Hydrology and Meteorology (DHM). Table 3 shows the hydro-meteorological network retained by the DHM.

Stations	Numbers
• Meteorological	442
• Aerosynoptic station	6
• Synoptic	9
• Agrometeorological	20
• Climatic Station	68
• Automatic Raingauge	51
• Manual raingage	286
• Hydrometric	154
• Automatic water level Recorder	40
• Manual Gauge	114
• Sediment Sampling	22

Table 3: Hydro-meteorological networks in Nepal (DHM 2008)

The DHM maintains cableways for hydrometric observations at 132 locations. The meteorological data have been processed till 2007 and the stream flow records are available up to 2006.

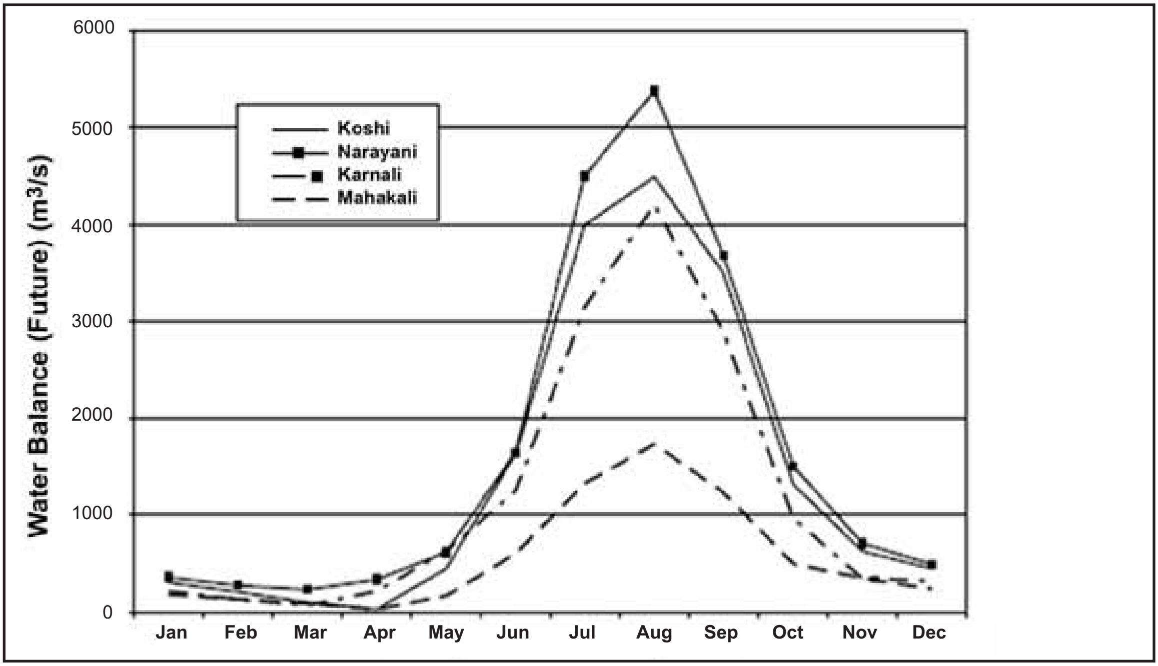


Figure 4: Water balance in the major basin

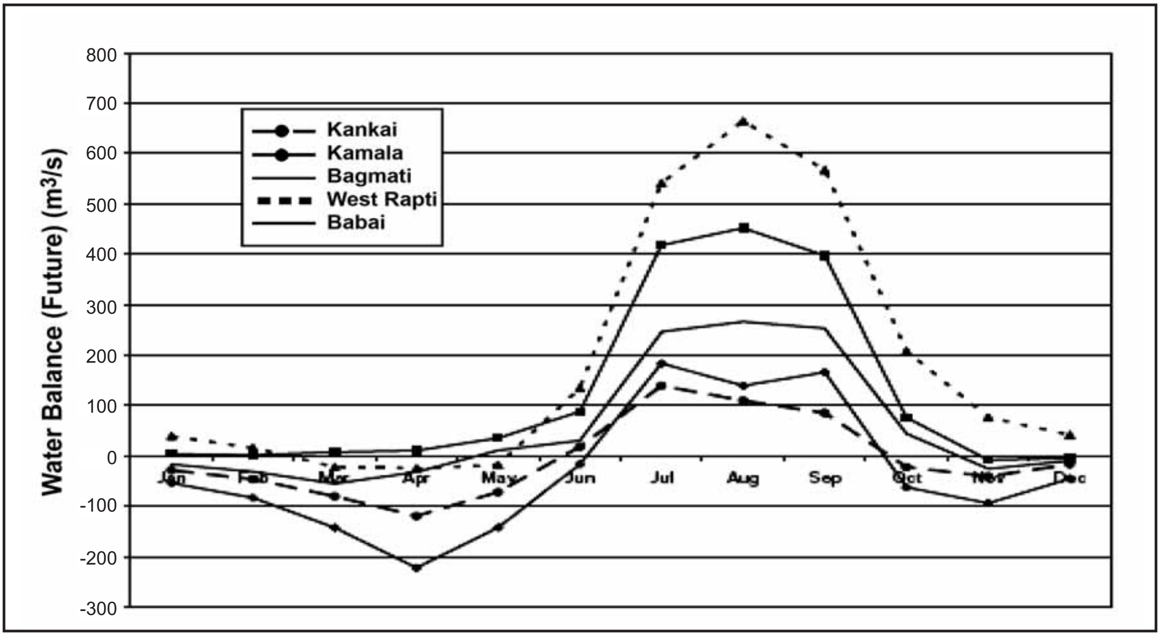


Figure 5: Water balance in the medium basins

3. Existing Water Use

Although Nepal has 225 BCM of water available annually, only a small part of it (estimated at 15 BCM) has so far been utilized for economic and social purposes. Out of this, around 95.9% has been used for agriculture, around 3.8% for domestic purpose and only about 0.3% for industry (ADB/ICIMOD, 2006). Until now, Nepal has utilized mainly the medium and small rivers for different uses such as drinking water, irrigation and hydropower. The larger and perennial Himalayan Rivers, except for a few run-of-the-river schemes, have been virtually left untapped. Since there is extreme seasonal variation in the availability of water in the rivers in Nepal.

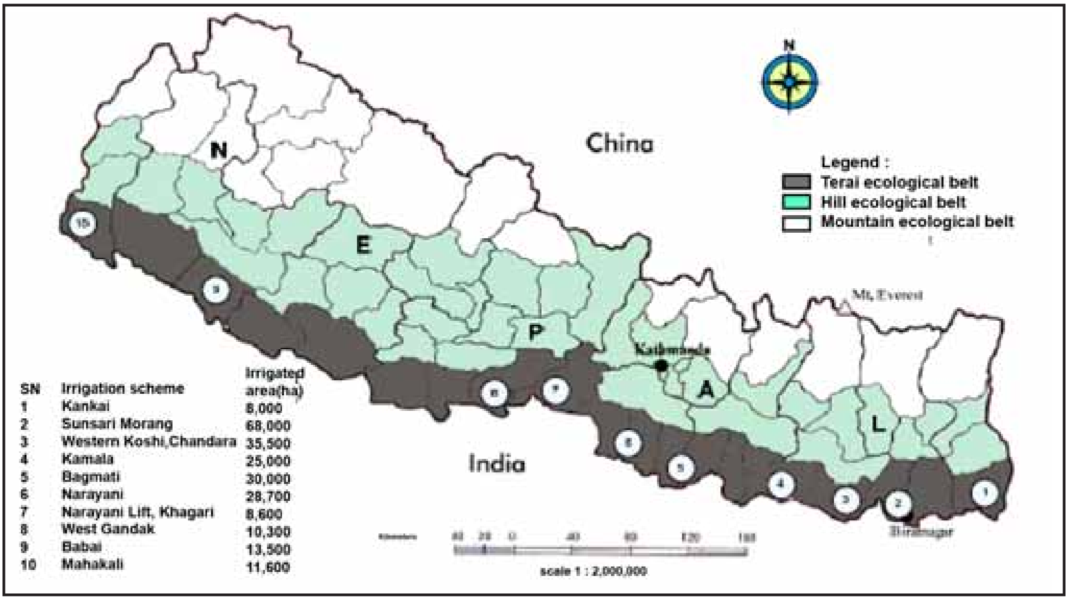
3.1 Irrigation Potential and Development

Irrigation is a major factor in the development of Nepal. It is the largest water use sub-sector, affects the life of many people involved in agriculture, the major contributor (40%) to the Gross Domestic Product (MOF, 2005) and a major factor for maintaining food security in the country. The government, from the very beginning, has wisely recognized this fact and given due importance to irrigation, both in its yearly and five-year plans. In the 10th five-year plan (2002-2007), 9.7% of the total national development budget was allocated to irrigation. Given the importance of irrigation and the large investments already made and planned for the future, the effectiveness of water delivery and its ultimate sustainability are of major concern.

The Water and Energy Commission Secretariat (WECS) indicates that many schemes have not reached their planned level of productivity and are not sustainable, financially as well as technically (WECS, 2003). In its plan for the future, the government wants the increment in irrigated area by constructing new schemes. At the same time, it is concerned about the efficiency, coverage area, cropping intensity as well as the recovery of the operation and maintenance costs of the existing irrigation schemes. Two types of activities would continue side by side for irrigation development – firstly, the modernization of the already constructed irrigation schemes and secondly, the construction of new schemes to provide irrigation for more land. The focus now is on modernization and the objectives of these works are:

- increase the performance of the schemes by providing more efficient water delivery,
- reduce the operation and maintenance costs by addressing the sediment control and transport issues,
- organize the farmers and impart training for scheme operation and maintenance and farm water management,
- provide agriculture extension services to increase productivity; and
- transfer the management of the scheme to the farmers depending upon their capability.

Nepal has a cultivated area of 2,642,000 ha (18% of its land area). Out of this, two-third (1,766,000 ha) is potentially irrigable. At present, 42% of the cultivated area has irrigation of some sorts but only 17% of the cultivated area has year-round irrigation (i.e. only 41% of the irrigated area gets year-round irrigation). In the Terai, 82% of the total irrigated area (889,000 ha) is through surface irrigation and the remaining 18% through groundwater. Most of the irrigated areas (and the future potential) are situated in the fertile lowlands of the Terai. It is estimated that the existing irrigation schemes contribute approximately 65% of the country's current agriculture production (WECS, 2003) as compared to the 40% crop output from 18% irrigated land in the world (Schultz B, 2002).



SN	Irrigation scheme	Irrigated area(ha)
1	Kankai	8,000
2	Sunsari Morang	68,000
3	Western Koshi,Chandara	35,500
4	Kamala	25,000
5	Bagmati	30,000
6	Narayani	28,700
7	Narayani Lift, Khagari	8,600
8	West Gandak	10,300
9	Babai	13,500
10	Mahakali	11,600

Figure 6: Map of Nepal showing the ecological zones and the major surface irrigation schemes (Poudel SN,2003)

Geographic region	Total area (10^3 ha)				Irrigated as % of cultivated	Year round irrigated as % of irrigated
	Cultivated	Irrigable	Irrigated	Year round irrigation		
Terai	1,360	1,338	889	368	65	41
Hills	1,054	369	167	66	16	39
Mountains	227	60	48	18	21	38
Total	2,642	1,766	1,104	452	42	41

Table 4: Irrigation potential and development in Nepal (WECS, 2003)

As shown in Table 4, around 62.5% of the potentially irrigable area has been provided with irrigation facilities. To irrigate the remaining areas, large-scale multipurpose land and water development projects have to be implemented. However, such projects need huge investments; otherwise, they are economically less viable. Even the existing schemes are running far below their target level. Around 90% of the command area is covered during the wet season. But, the coverage is only around 25% during the dry season. This is due to the high seasonal variation in the water available in the streams. Most of the small- and medium-scale schemes take water from the small- to medium-sized streams and are affected the most. The coverage during the dry season is nominal even for large-scale schemes from snowfed perennial rivers due to design and operational limitations. Even if the large-scale multipurpose storage and inter-basin river diversion projects were implemented with great urgency over the next twenty-five years, there would still be 55% of the irrigable arable land non-irrigated between November and May in 2025 (Shah and Singh, 2001).

None of the irrigation systems in Nepal measure the quantum of water supplied to irrigation. The only available data are (i) annual diversion requirements for monsoon and year-round irrigation based on physiographic regions (ii) irrigation command areas split into seasonal (monsoon) and year-round. The Agriculture Perspective Plan (APP) estimated the water use for irrigation with a total of 17,000 million cubic meters which is less than 8% of the country's total water resource potential.

The present focus has been to develop quick yielding small irrigation systems. Despite considerable investments in infrastructure development and a well-trained cadre of technicians for their design, development, operation and management, the public sector irrigation schemes have been performing below expectations. The irrigation efficiency is around 30%, the crop productivity is stagnant or declining and the problem of system management still remains an issue.

Through a series of interaction workshops between experts, irrigation professionals, planners and political leaders, the WECS has identified some key issues in the irrigation sector that can be summarized as:

- Reorientation of the supply driven approach,
- Poor performance of irrigation schemes,
- Lack of effective implementation of the Agricultural Perspective Plan (APP),
- Farmer's dependency syndromes and sustainability,
- Problems of river management,
- Weak institutional capability,
- Symbiotic relationship between agriculture and irrigation (weak linkages); and
- Strengthening of Water Users Associations (WUA).

3.2 Groundwater and its Utilization

The available information show that a good potential for groundwater extraction exists in the Terai and the inner valleys in the hills and mountains. Much of the Terai and some parts of the Siwalik valleys are dominated by shallow or deep aquifers, many of which are suitable for exploitation as sources of irrigation and drinking waters. Their annual recharge estimates range from 124 to 685 mm (NENCID, 1999). The corresponding volume of water available for groundwater extraction is estimated to be between 5.8 BCM and 12 BCM. However, based on the measurement of the seasonal fluctuations in the water table in shallow tube-wells, the groundwater reserve is reported to be about 8.8 BCM annually.

The groundwater resource estimates are mainly available for the Kathmandu Valley, the Inner Terai valleys like Udayapur, Chitwan, Deukhuri, Dang, Surkhet and the main Terai. However, the groundwater estimates for the springs and dug-wells in the hills and mountains have not been made up-to-date. There have been various estimates of the groundwater resources. For example, in the Kathmandu Valley, the annual rechargeable estimates vary from 4.75 mcm to 13.65 mcm per annum. In addition, the static reserve is estimated to be anywhere between 21.6 mcm to 3,250 mcm. The five inner Terai valleys listed above are estimated to contain good groundwater potential. The estimates for Chitwan, Deukhuri and Dang are about 136-421 mcm/annum, 133 – 181 mcm/annum and 130-140 mcm/annum (from shallow tube-wells alone) respectively (WECS, 2003). The estimates for Udayapur and Surkhet have yet to be reliably arrived at. As of now, around 1,300 Deep Tube-wells (DTW) and 50,000 Shallow Tube-wells (STW) - excluding hand, rower and treadle pumps - have been installed in the country.

3.3 Hydropower Development

The estimated hydropower potential of Nepal is 83,000 MW. Out of this estimated potential, 114 projects with a combined capacity of 45,610 MW have been identified as economically feasible. The recent estimate - at 40% dependable flows - for the run-of-the-river (ROR) hydropower potential in Nepal stands at 53836 MW. In this estimate, specific discharge (with reference to the gauged river location) was used to account for the spatial variation of the flow in the various stream networks. However, the discharge along the river stretch does not vary linearly with respect to the catchment area. This is mainly due to the high spatial variation in rainfall over the country. The estimate could therefore be different if discharges at various locations are estimated using the spatial variation in the rainfall distribution over the area.

The Integrated Nepal Power System (INPS) is primarily managed by the Nepal Electricity Authority (NEA). At present, the NEA has a total installed electricity generation capacity of about 689 MW. Out of this, the hydropower capacity stands at 632 MW.

River Basin	Name	Capacity (MW)
Bagmati	Kulekhani I* Kulekhani II*	60.0 32.0
Rapti	Jhimruk	12.3
Koshi	Panauti SunKoshi Indrawati Khimti BhoteKoshi	2.4 10.5 7.5 60.0 36.0
Kankai	Puwa	6.2
Narayani (Gandak)	Trisuli Devighat Gandak Marsyangdi Middle Marsyangdi Andhikhola Chilime Kali Gandaki A Modi	24.0 14.1 15.0 69.0 70.0 5.1 20.0 144.0 14.8

Table 5: Existing hydropower plants (NEA, 2009)

In addition to these existing plants, some hydropower projects are scheduled to be commissioned. Among others, these include the 309 MW Upper Tamakoshi, the 60 MW Upper Trishuli A, the 37 MW Upper Trishuli B, the 128 MW Upper Trishuli and the 14 MW Kulekhani III.

The country hopes to bring about hydropower development through three strategic considerations. These include the building up of large-scale storage projects envisaged primarily for exporting energy, medium-scale projects for the meeting of national needs and small-scale projects catering to the local communities. Currently, four major storage projects are proposed as Indo-Nepal cooperative initiatives. These are the Chisapani-Karnali (10,800 MW), the Pancheswor (6480 MW), the Budhi Gandaki (600 MW) and the Sapta Koshi High Dam (3600 MW). These four projects would, in total, provide 22,200 MW of installed capacity. The recent policy of the NEA promotes both external and domestic private sector initiatives for hydropower development.

Project Name	Capacity (MW)	Cost million USD	Year of Study
Karnali (Chisapani)	10,800	7,666	Updated in 2001
Pancheswor	6,480	2,980	1995
West Seti	750	1,098	1997
Arun-III	402	859	1991
Upper Tamakoshi	309	464	May 2005
Upper Karnali	300	454	1998
Dudhkoshi	300	690	1998
Andhi Khola	176	463	1997
Tamur-Mewa	101	191	1998

Table 6: Large hydropower projects with feasibility study (WECS, 2003)

Nevertheless, the peak power and energy demand is growing by about 11% annually. This has created huge electricity shortages in Nepal. To meet the significant difference between the demand and the supply, the NEA increased power cuts in the country for upto 18 hours a day in January 2009. The system load curve and load-shedding amount during that period is shown in Figure 7.

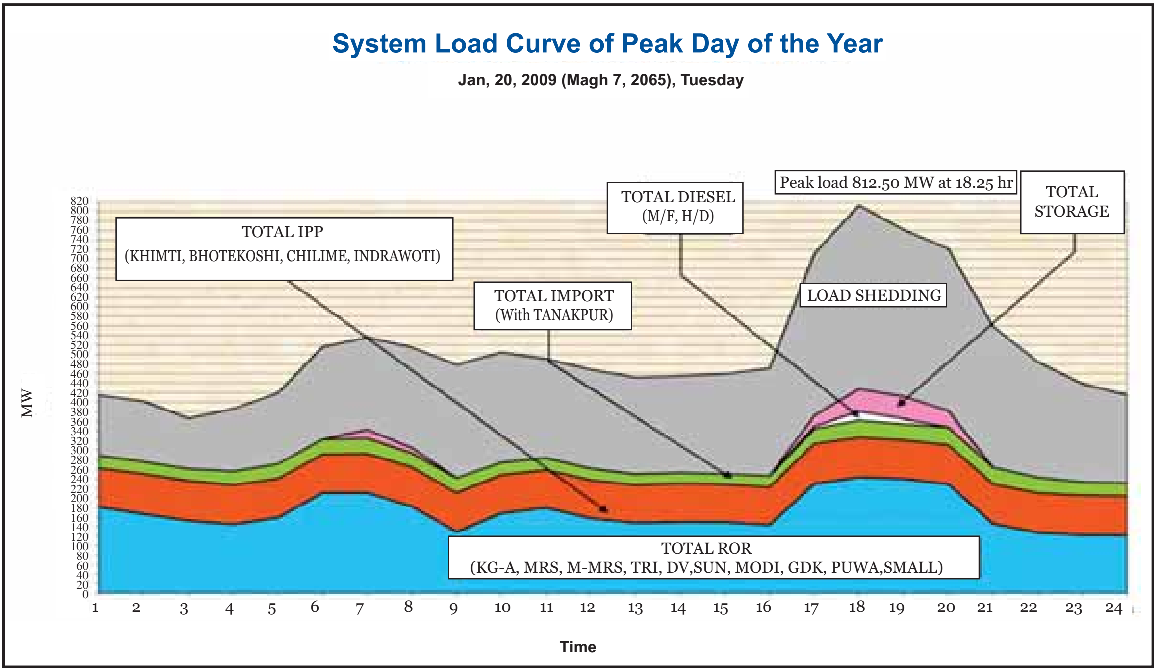


Figure 7: Load curve on peak demand day of the year 2009 (NEA, 2009)

With the exception of the Kulekhani Power Plant, all of the existing and future (scheduled to be commissioned by the next five years) hydropower plants are run-of-the river types which are designed for dry season flows (i.e. minimum flows). Hence, the load-shedding hours during the dry season depend on the availability of water in the Kulekhani reservoir. In February 2008, the Nepal government formed a committee in order to solve this problem of load-shedding. As some of the solutions, this committee proposed the development of storage projects like the upper Seti, speeding up of the construction of the Upper Tamakoshi, the Upper Trisuli A, the Upper Trisuli B, Kulekhani III and the encouragement of IPP's for hydropower development.

The country possesses an in-country capacity of developing medium-sized hydropower projects with a power generation capacity of up to 50 MW. It has also been demonstrated that such domestically developed schemes are highly cost-effective and could easily compete with the costs of production in the rest of the subcontinent. Hence, Nepal must strive towards creating a more conducive environment in order to accelerate the development of its in-country capacity. It should also actively encourage investments in the hydropower sector. The state should also promote extensive rural electrification, particularly in the Terai where micro-hydro schemes are not possible. This provides an additional economic benefit to the power sector as it will also open up a huge consumer base that will use the country's surplus power, if any.

At the same time, the promotion of electricity-intensive industries can further encourage hydropower generation. Moreover, the value-added products from such industries can become competitive in the regional and global markets. In the current scenario, large-scale hydropower projects are feasible in Nepal only when India is prepared to buy the power thus generated at commercial rates and to share the benefits accrued by way of downstream benefits in the case of storage dam projects. The communities and private sector institutions in Nepal too are actively engaged in developing renewable energy resources, including hydropower.

At present, the electricity generated from the various systems supply power to 40% of the households in the country. The share of power supply from the community or private sector-owned systems stands at 17% of the total. In Nepal, hydropower schemes of up to 1 MW do not require any license for development. Neither do they need to pay any income tax on the revenue thus generated. These schemes, however, need to be registered with the concerned district administration office. This government policy has greatly helped propagate decentralized small and micro hydropower systems in the hilly and mountain districts of Nepal. In recent years, such micro hydro projects have helped meet the community's minimum electricity need.

This has contributed substantially in improving the quality and standard of living in the remote areas. However, there is a regulation which stipulates that if the water sources are located within the forested area, national parks, wildlife reserves and conservation areas, the hydropower developer should follow working policy of the Ministry of Forest and Soil

Conservation (MoFSC), GoN, 2065, even for the development of a scheme generating less than 1MW. Many developers have felt it practically very cumbersome to comply and get clearance from the MoFSC in this regard. The working policy also prohibits the connection of energy produced from such locations to the national power grid. In addition, there is the provision which requires the downstream release of 50% of the monthly natural flow. This obviously restricts the diversion for power generation.

Keeping in the above mentioned views, the targeted development plan for hydropower by 2017 included:

- Up to 2,035 MW hydropower electricity is developed to meet the projected domestic demand at base case scenario, excluding export,
- 50% of the households are supplied with INPS electricity, 12% by isolated (micro and small) hydro systems and 3% by alternative energy,
- Per capita electricity consumption of 160 KWh is achieved; and
- NEA is corporatized**.**

And by 2027

- Up to 4,000 MW of hydropower is developed to meet the projected domestic demand at base case scenario, excluding export,
- 75% of the households are supplied with INPS electricity, 20% by isolated (micro and small) hydro systems and 5% by alternative energy,
- Per capita electricity consumption of over 400 KWh is achieved,
- Substantial amounts of electricity exported to earn national revenue; and
- NEA unbundled and privatized.

3.4. Water Supply and Sanitation

At present, only about 72% of the country's population has access to basic water supply. Moreover, most of the urban water supply systems are not delivering an efficient and effective service. In the rural areas, the government policy has been to hand over the management of the Department of Water Supply and Sewerage (DWSS)-built systems to the concerned communities. In spite of this, many rural water schemes are not functioning properly. So, currently, the government is planning to rehabilitate and upgrade more than 500 such schemes and hand them over to the concerned communities for operation and maintenance (O&M). The sanitation sector too is lagging far behind in Nepal. In fact, only 25% of the whole population has sanitation facility. Even the few sewerage systems in existence/operation are not functioning satisfactorily. At present, the water supply and the sanitation programs have been tied up together. As a result, things are gradually improving in the latter. Public health education programs are also being integrated with the drinking water and sanitation programs. For water supply and sanitation, the National Water Plan 2005 targets:

By 2012

- 90% of the population has access to water supply,
- 50% of the population has medium or high water supply service level; and
- 90% of the population has access to basic sanitation facilities.

By 2017

- 100% of the population has access to water supply,
- 27% of the population has medium or high water supply service level; and
- 100% of the population has access to basic sanitation facilities.

By 2027

- 50% of the population has medium or high water supply service level.

4. Water-induced Disasters

The Himalaya of Nepal is geologically active where the instabilities due to tectonic activity and ongoing erosion are apparent everywhere. These factors, combined with the peculiar meteorological conditions where both the rainfall and river flow vary tremendously in both time and space, make the landscape vulnerable to water-induced disasters such as floods, landslides, slope failures, river bed variation (resulting in subsequent shifting and degradation) and debris flow.

In addition to these natural processes, development activities and increasing population have caused further vulnerability and destabilization of land resources. This includes human activities such as deforestation, cultivation of marginal land, road building in the hills and mountains and the encroachment of floodplains. Water-induced disasters, thus, have been occurring more frequently in recent times. Statistics indicate that 6,025 people have lost their lives in floods and landslides between 1983 and 2001. The estimated economic losses from these calamities amounted to around NRs 11,860 million (MoPE 2004).

In Nepal, devastating floods are triggered by different mechanisms which can be classified into five major types: i) continuous rainfall and cloudburst (CLOF) ii) glacial lake outburst flood (GLOF), iii) landslide dam outburst flood (LDOF) iv) floods triggered by the failure of infrastructure v) sheet flooding or inundation in lowland areas due to an obstruction imposed against the flow (Dixit 2003; Khanal NR 2005).

4.1. Continuous rainfall and cloudburst (CLOFs)

Floods are common throughout the country in the latter stages of the monsoon when the land is saturated and the surface runoff increases. Extremely high intensity precipitations in mountain areas cause landslides on mountain slopes and debris flows and floods along the river valleys. Extreme precipitation events that occurred between 1948 and 1955 caused landslides and debris flows in the mountain areas. They, consequently, led to destructive floods on many rivers in the lowland areas. The highest flood recorded occurred in the Koshi River in 1954 and was the result of widespread rainfall in its mountain catchment area (Dixit A. 2003). The livelihood options for many families in the mountain areas were threatened. As a response, in 1956, the government began resettlement programs for the severely affected families in the Inner Terai and Terai regions.

At the same time, spontaneous large-scale migration from the mountains to the Terai and from the ridges to the river valleys took place immediately after the implementation of a malaria eradication program in the lowland areas (Khanal NR. 2004). Between 1981 and 1998, three events of extreme precipitation with extensive damage have been reported (Chalise SR. and Khanal NR. 2002). Devastating floods associated with high intensity precipitation and consequent landslide and debris flow activities in the mountain terrain occurred in Lele (Lalitpur district) on September 30, 1981; in the Kulekhani-Sindhuli area on July 19-20, 1993; and in Syangja District on August 27, 1998. In the second of these events, the loss of life and property was not confined to the mountain areas where high-intensity precipitation had taken place; hundreds of people were also swept away in the downstream areas as far away as Rautahat and Sarlahi districts in the Terai.

4.2. Glacial lake outburst floods (GLOFs)

Glacial lakes are common in the high mountain areas in Nepal. A recent study shows that there are 3,252 glacial lakes in Nepal (Mool P. et al., 2001a). It also identified 21 GLOF events. Thirteen of these occurred between 1964 and 1998; nine occurred in the Tibetan

Autonomous Region (China). The latter affected the areas downstream along transboundary rivers like the Sun Koshi, Arun, and the Trishuli in Nepal. A GLOF damaged a hydropower plant and many houses along the former in 1981. In 1985, a similar event swept away three persons, one hydropower plant, 14 bridges and 35 houses along the Dudh Koshi River. Nearly 26 glacial lakes have been identified as potentially dangerous.This renders much of the infrastructure along the rivers originating from these lakes at immediate risk.

4.3. Landslide dam outburst floods (LDOFs)

The formation of temporary lakes due to landslide damming is a common phenomenon in the high mountain areas where there are very narrow river channels and steep mountain slopes. Eleven disastrous floods caused by the breaching of landslide dams have been reported in Nepal between 1967 and 1989 (Khanal N.R. 1996). The Budhi Gandaki River near Lukubesi (1968), the Sun Koshi River near Barhabise (1982), the Balephi Khola in Sindhupalchok (1982) and the Gyangphedi Khola, Nuwakot (1986) were dammed by landslides. The resultant outburst floods took a heavy toll of human lives and infrastructure.

4.4. Floods triggered by infrastructural failure

The floods triggered as a result of poor infrastructural design are also common in Nepal. Eight such floods have been reported. The failure of check dams and embankments in Butwal in 1981 led to loss of 41 lives, 120 houses and one bridge being swept away (ICIMOD, 2007). Similarly, in 1990, 26 people and 880 houses were swept away by a flood triggered by the failure of a check dam on the Rapti River in Chitwan. In 1993, the Bagmati River was dammed for a few hours because of blocking by tree logs at the Bagmati barrage; the ensuing outburst flood swept away 816 people in Rautahat and Sarlahi districts. The Larcha River was dammed by a boulder at the bridge over the highway in 1996; the subsequent outburst flood swept away 54 persons and damaged 22 houses (ICIMOD, 2007).

4.5. Sheet flooding

Sheet flooding or inundations are common during the monsoon in lowland areas in the Terai. The risk of such hazards has been increasing in recent years as a result of the increasing development of infrastructures such as roads, culverts, check dams etc. and the consequent obstruction in the natural flow of the surface runoff. Moreover, the unilateral construction of roads perpendicular to the natural flow of rivers near the border area between India and Nepal without sufficient drainage and construction of barrages, dams, afflux bunds and dykes have also exacerbated flooding in Nepal.

More than ten cases of such infrastructure-induced flood disasters have been reported near the border area. Although the loss of life is comparatively low in the Terai districts, the extent of impact is very high in terms of the number of families affected and the loss estimated. Districts such as Rautahat, Sarlahi, Mahottari and Dhanusa located in the Central Terai are seriously affected by floods. A comparison of the loss and damage incurred between 1970 and 1993-2002 (Khanal NR. 2005). It shows that since 1992, the Central and Eastern Terai have been experiencing increasing losses from water-induced disasters. Along with Sindhuli District in the mid-hills, the Central Terai districts of Rautahat, Sarlahi, Mahottari and Dhanusa have been repeatedly and seriously affected by floods.

5. Assessment of Climate Change Impacts

The water resources system is very sensitive to climate change. Climate change has an impact on such important natural phenomena as precipitation, flood and the water supply in rivers. They, in turn, directly or indirectly affect factors as fundamental as biodiversity, food production, health and power generation. The assessment of these impacts is very essential for an efficient, effective and sustainable planning of water resources. Besides, water is getting increasingly scarce. Hence, the planners and managers concerned need to be aware of the impacts of climate change on water resources.

The assessments of climate change impacts are generally done by using models. The input parameters and data for the models are crucial in the assessment of impacts through model study. Besides the shortage of technical support and experts, the lack of a continuously long series of data is the major challenge in the assessments of these impacts.

5.1. Precipitation Change

The precipitation records of Nepal, based upon 78 stations for the period between 1948 to 1994, show a large variability in both the inter-annual and decadal precipitation. However, the magnitudes of the long-term precipitation trends are lower when compared to these time scales. Nepal monsoon record is highly correlated with the Southern Oscillation Index (SOI) series. The exceptionally dry year of 1992 recorded in Nepal coincides with the elongated El Niño-Southern Oscillation (ENSO) of 1992-1993 and the Mount Pinatubo eruption in 1991 (Shrestha AB. et al., 2000).

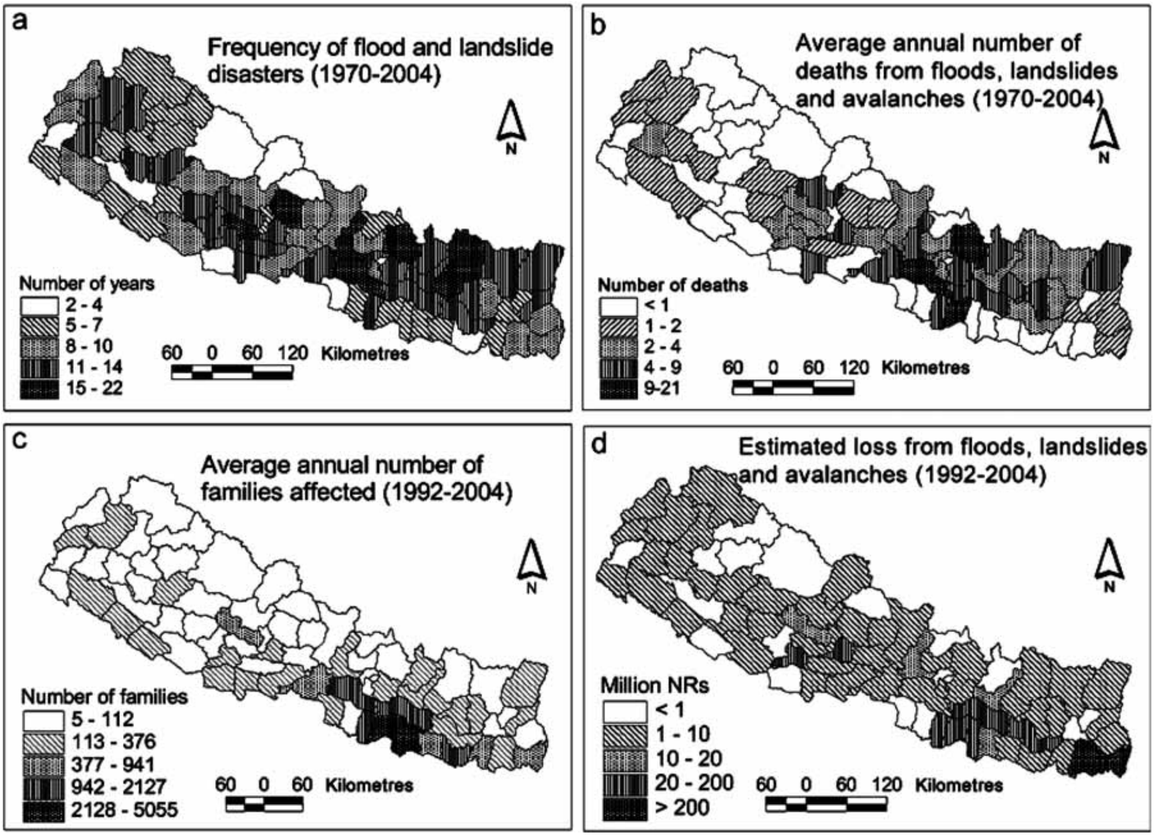


Figure 8: Flood and landslide disasters in Nepal (Khanal, 2005)

According to the precipitation trend analysis based upon the data of 80 stations in Nepal, most of the Terai area and Western Nepal observe a negative precipitation trend (Figure 9). The hills and mountains of Western Nepal and the northern part of Eastern Nepal have a positive trend with a maximum increase of 1100 mm/decade. Based on data from 1947 to 1993, Sharma KP. et al. (2000) found that the precipitation trend in the Koshi Basin (Eastern Nepal) shows an increasing trend. On the other hand, the eastern and central part of Nepal face a negative trend of <700 mm/decade. The overall average trend for Nepal indicates that the annual average precipitation over Nepal is decreasing at the rate of 9.8 mm/decade (MoPE, 2004).

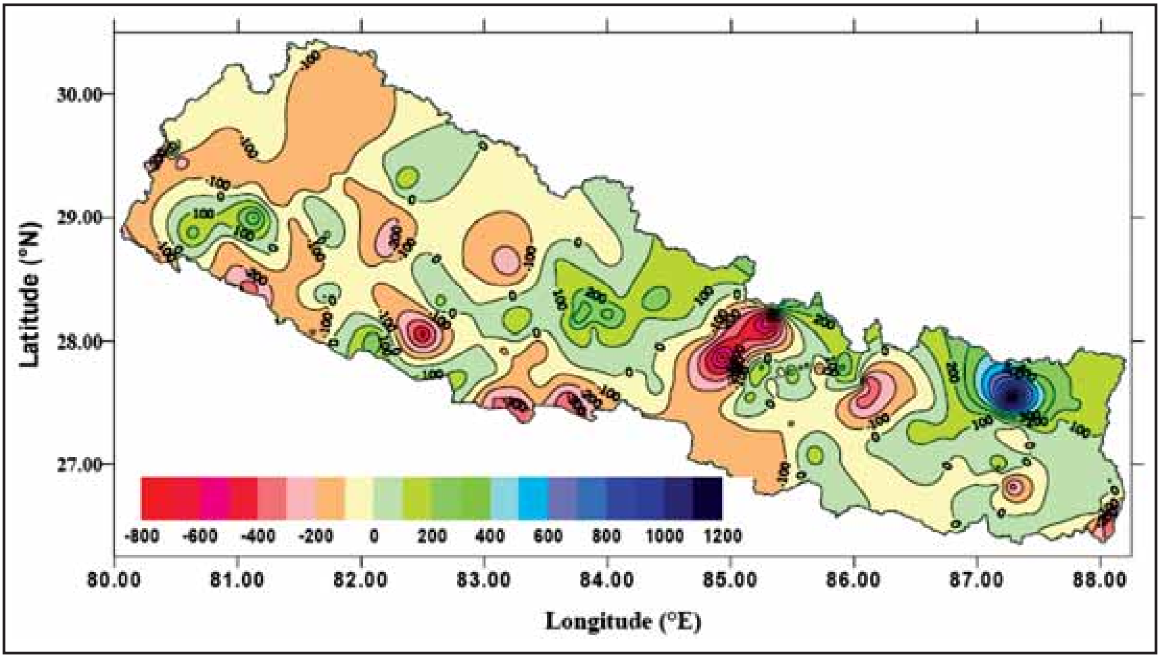


Figure 9: Trend of per decade annual precipitation (mm) for the period 1981 to 1998 (MoPE, 2004)

5.2. Impacts on Water Availability

The water availability at any location within a river system is estimated by analyzing the local hydrology of the basin under consideration. Although climate change is a global phenomenon, its impact on the local hydrology is considerable.The hydrological seasons in Nepal can be categorized into three different groups: (a) dry pre-monsoon season (March–May) with almost no rain (b) rainy monsoon season (June–September) (c) post-monsoon season (October–February) with little rain. As shown below in Table 7, the specific discharges of the rivers in Nepal are not uniform for all the rivers but vary randomly.

Climate change will significantly increase the intra-annual variability of stream flow (Agrawala et al., 2003). For example, a study by Chaulagain NP. (2006) has shown that for a temperature rise of 4ºC and a precipitation increase of 10%, the range of flow (i.e. the difference between the highest and the lowest flows) in the Bagmati River would increase from the present 268 m^3/s (i.e. from 7.3 m^3/s to 275.3 m^3/s) to 371.6 m^3/s (i.e. from 6.9 m^3/s to 379.6 m^3/s).

The MoPE (2004, p.99), using the *WatBal* model, revealed that for an increase in temperature of 4% and an increase in precipitation of 10%, the runoff in the Karnali, Narayani, Koshi and the Bagmati Rivers in Nepal would increase by 1%, 9%, 5% and 11% respectively. The simulation of this model in another study revealed that for an increase in temperature of 4ºC and an increase in precipitation of 10%, the runoff in the Bagmati River at Chobhar and the Langtang Khola in Langtang would increase by 3.8% and 2.2% respectively (Chaulagain NP. 2006).

The trend in the annual discharges of the Koshi, Gandaki and the Karnali Basins indicate that the discharges in these major basins are decreasing annually. By contrast, as shown in Figure 10, the annual discharges in the southern basins show an increasing trend (Shrestha KL. et al., 2003). The Bagmati Basin, originating in the middle mountain region, also shows a decreasing amount in the annual flow of the river. Also, through the viewing of the historical series of monthly data, it has been noted that while the flow in the monsoon season (June - September) is decreasing, it is increasing for the other months.

S.N.	River	Specific discharge ($m^3/sec/km^2$)		
		Maximum	Minimum	Average
1	Karnali	0.042	0.022	0.034
2	Babai	0.003	0.001	0.002
3	West Rapti	0.004	0.002	0.003
4	Narayani	0.045	0.029	0.037
5	Bagmati	0.004	0.002	0.003
6	Koshi	0.038	0.027	0.033
7	Kankai	0.002	0.001	0.001

Table 7: Specific Discharge of some of the river basins in Nepal (Shrestha KL. et al., 2003)

The trend analysis has shown that in the eastern and far-western mountains, the aerial averages of the flow have a decreasing trend. However, in the central and western mountains, there is no significant impact of climate change on the annual rainfall and the eventual annual discharge. The increasing trend in the annual responses of the Babai and Rapti Basins are mainly due to the increasing trend in the amount of monsoonal rainfall over the mid-western hills of Nepal. The analysis therefore shows that climate change has affected Nepal with less monsoonal rains across the high mountains and more monsoonal rains along the southern hills.

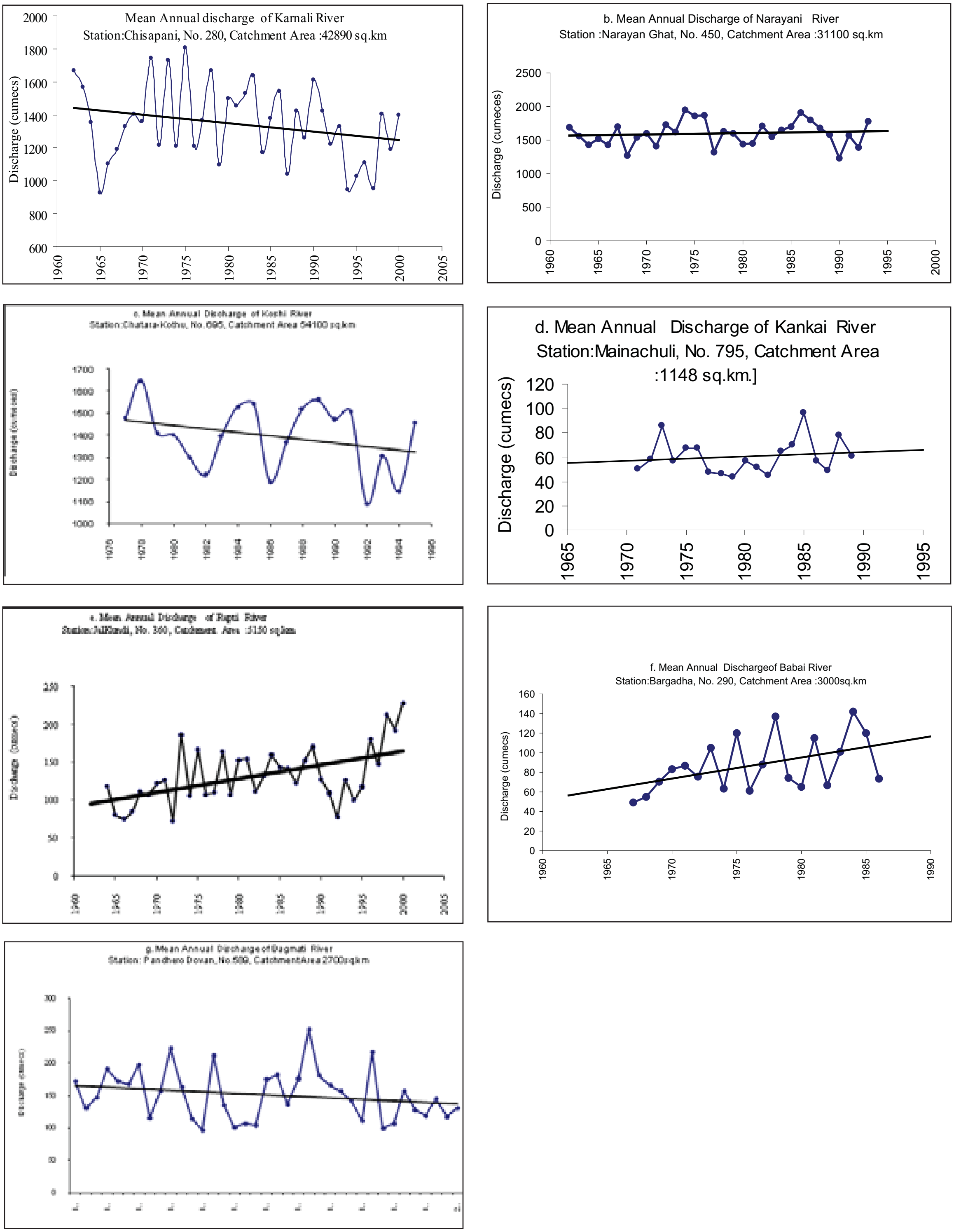


Figure 10: Trend of annual discharge of the major rivers of Nepal (Shrestha et al., 2003)

The hydrology of both the snowfed and non-snowfed river systems is apparently distinctive during the melting season. It is very important to note that during the lean season, the snow and glacier melts have significant effect on the hydrology of the river systems in Nepal. The effects of the warming trends can be recognized by comparing this noticeable hydrology of these two systems. The trend analysis of the monthly flow in the two adjacent snowfed (Modi and Myagdi) and two non-snowfed (Badi Gad and Andhi Khola) sub-basins in the Kali Gandaki Basin (Figure 11) indicate that there is an increasing trend in the runoff of the former during the months of April and May. By contrast, it is exactly opposite for the latter. This implies that there is an increasing trend in the melting of snow and glaciers in these sub-basins. However, the wet season flows have an apparently increasing trend in all the sub-basins. Such typical impact mainly due to climate change is being experienced in most of the basins and sub-basins in Nepal.

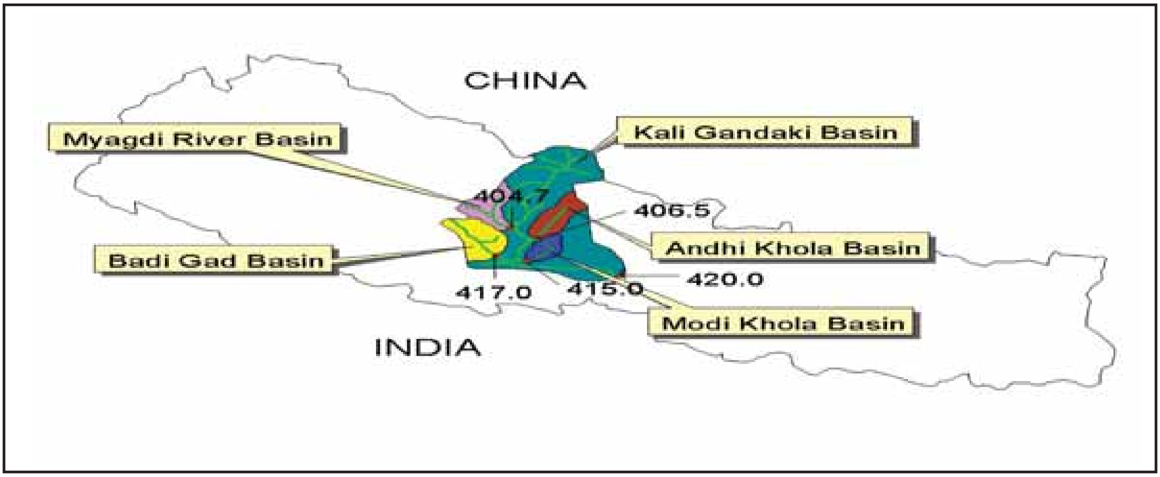


Figure 11: Location of river basins selected for monthly flow trend analyses

The trends in the monthly flows of the Myagdi River for the period of 1975-2000 are shown in Figures 12 & 13. Those for the Modi River during the same period are shown in Figures14 & 15. Similarly, the trends in the monthly flows of the Andhi Khola are shown in Figures 16 & 17 and those for the Badi Gad Khola are shown in Figures 18 & 19.

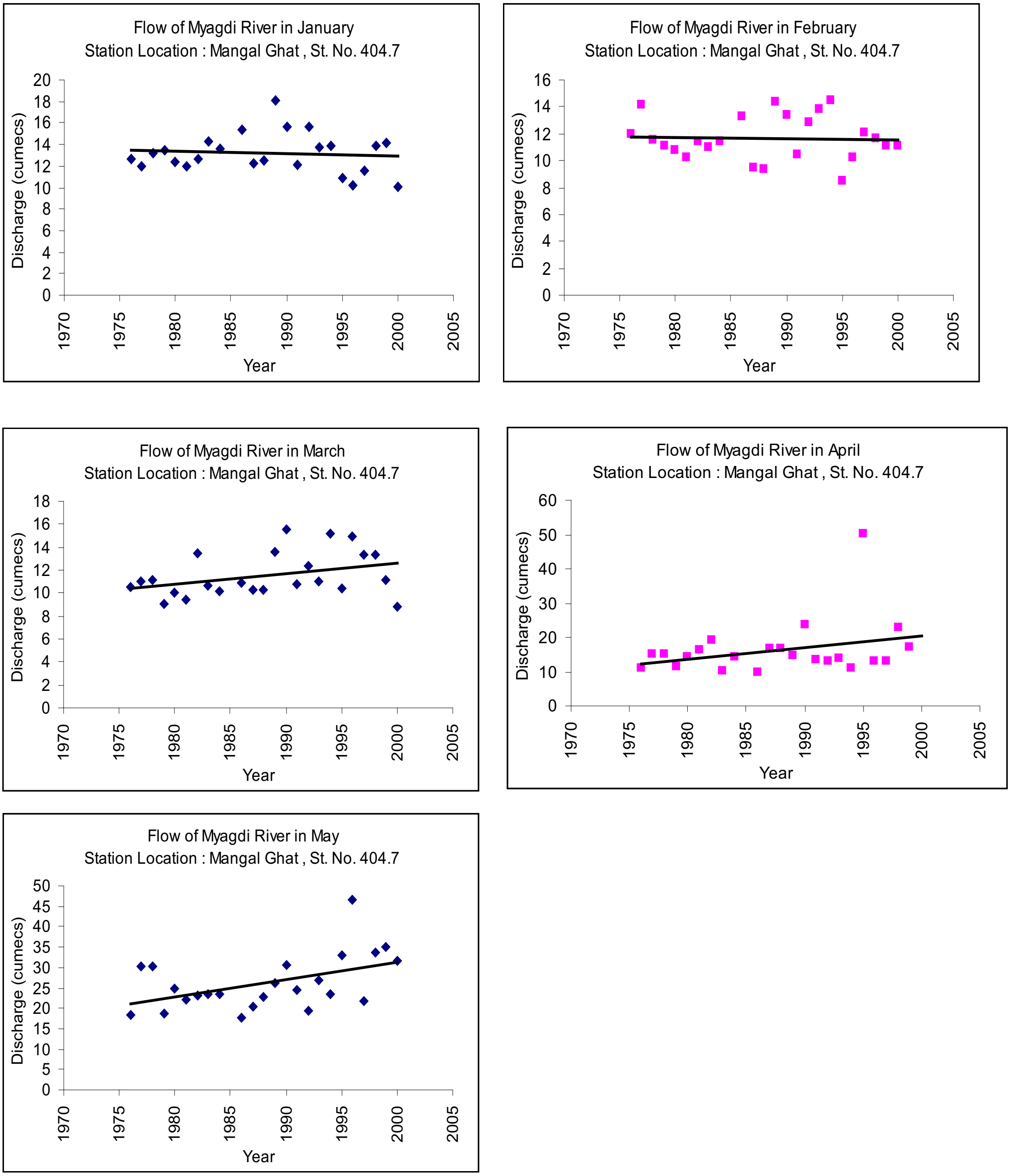


Figure 12: Monthly trend of the flow observed in the Myagdi River at Mangal Ghat Station 404.7 (Jan.-May)

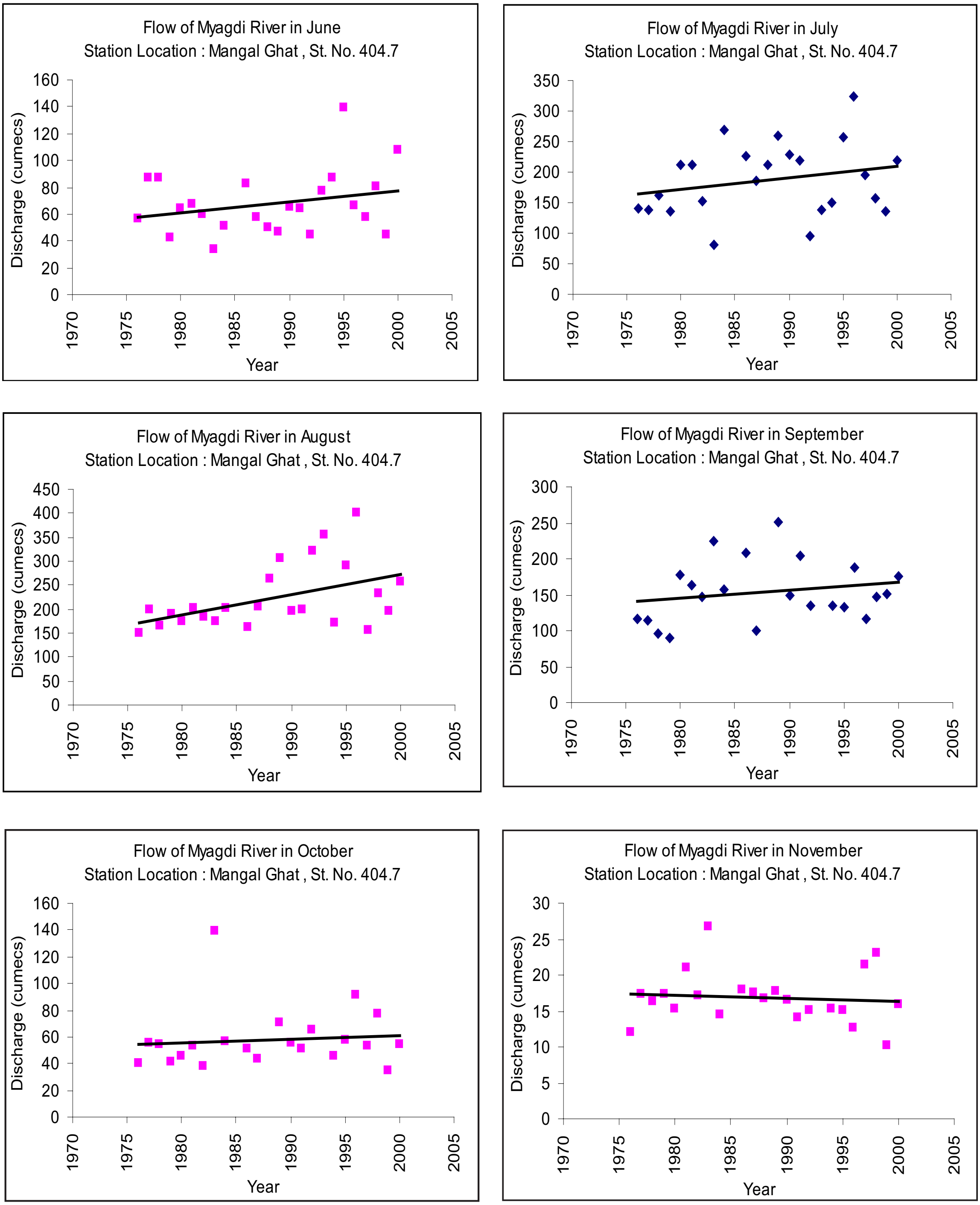
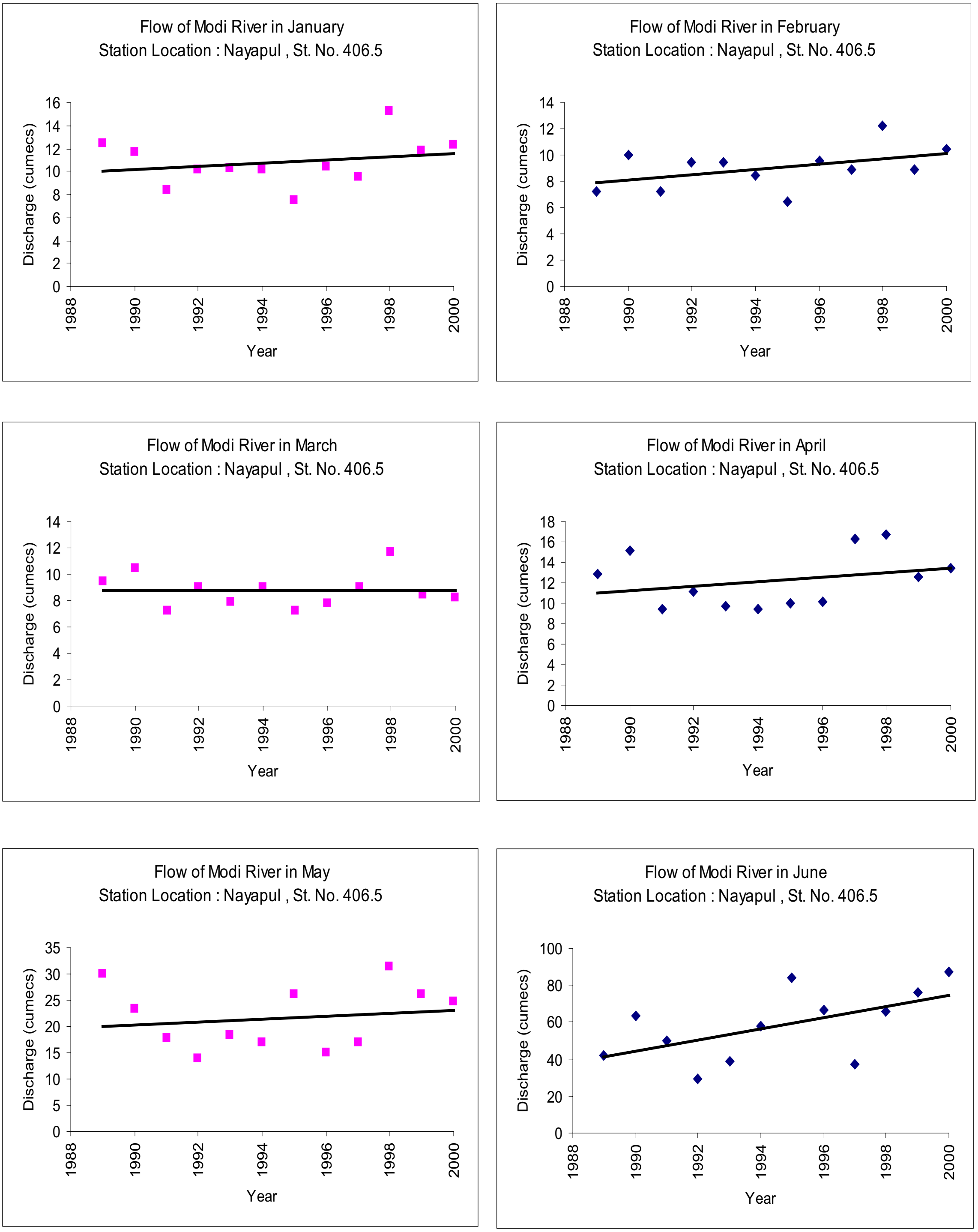


Figure 13: Monthly trend of the flow observed in the Myagdi River at Mangal Ghat Station 404.7 (July-Dec.)



Flow of Modi River in January
Station Location : Nayapul , St. No. 406.5

Flow of Modi River in February
Station Location : Nayapul , St. No. 406.5

Flow of Modi River in March
Station Location : Nayapul , St. No. 406.5

Flow of Modi River in April
Station Location : Nayapul , St. No. 406.5

Flow of Modi River in May
Station Location : Nayapul , St. No. 406.5

Flow of Modi River in June
Station Location : Nayapul , St. No. 406.5

Figure 14: Monthly trend of flow observed in the Modi Khola at Nayapul Station 406.5 (Jan.-June)

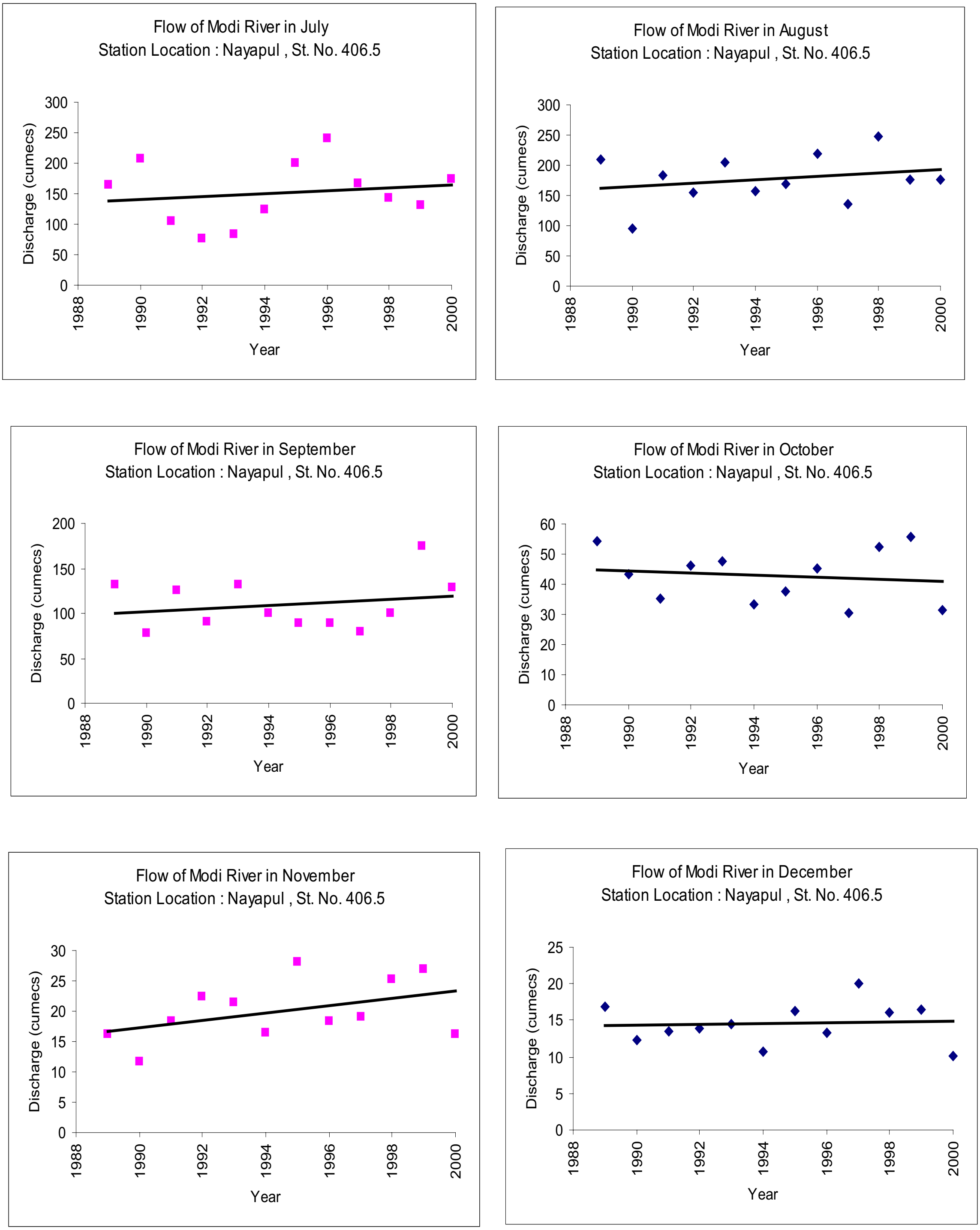
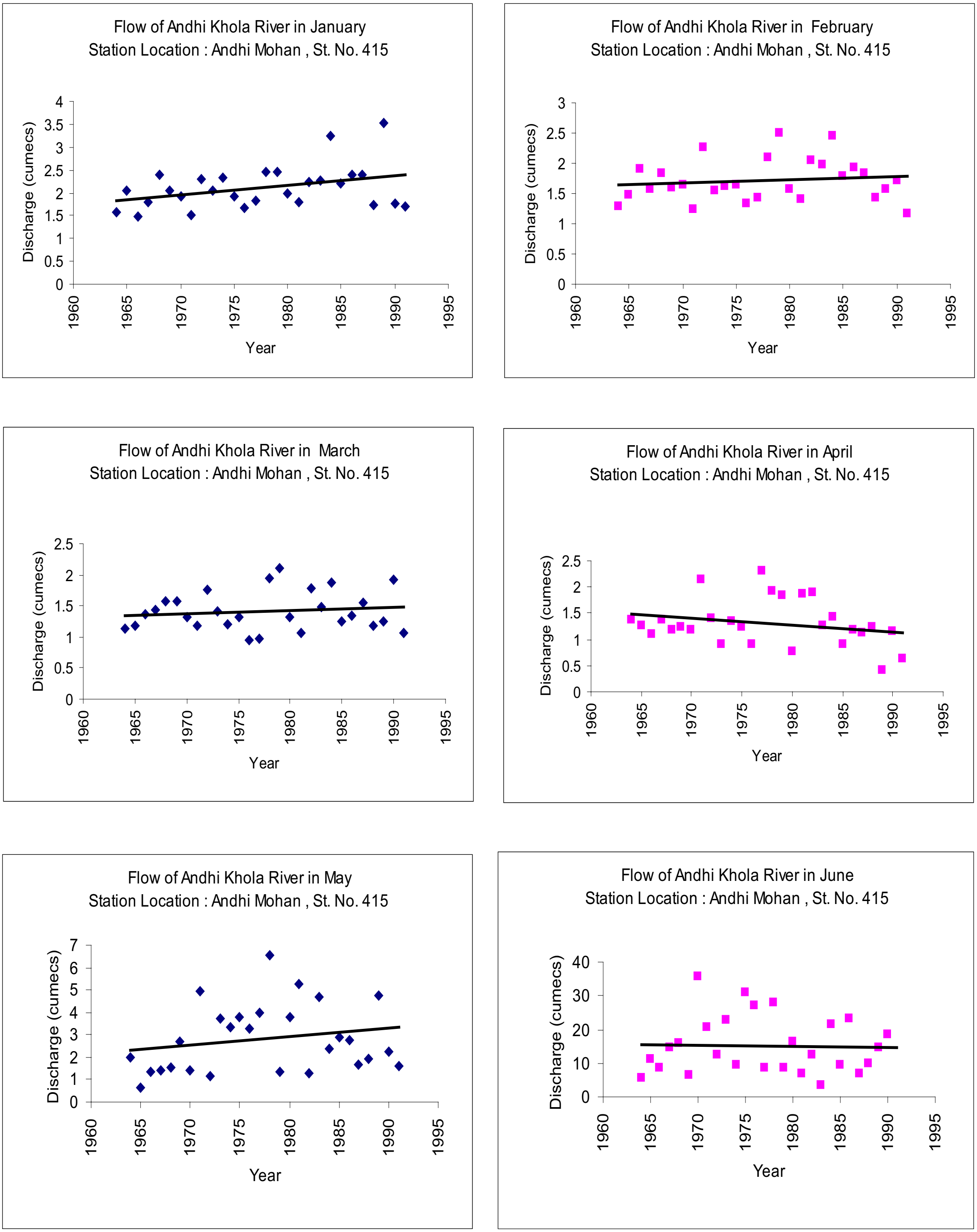


Figure 15: Monthly Trend of the flow observed in the Modi Khola at Nayapul Station 406.5 (July-Dec.)


Flow of Andhi Khola River in January
Station Location : Andhi Mohan , St. No. 415

Flow of Andhi Khola River in February
Station Location : Andhi Mohan , St. No. 415

Flow of Andhi Khola River in March
Station Location : Andhi Mohan , St. No. 415

Flow of Andhi Khola River in April
Station Location : Andhi Mohan , St. No. 415

Flow of Andhi Khola River in May
Station Location : Andhi Mohan , St. No. 415

Flow of Andhi Khola River in June
Station Location : Andhi Mohan , St. No. 415

Figure 16: Monthly Trend of the flow observed in the Andhi Khola at Andhi Mohan Station 415 (Jan.-June)

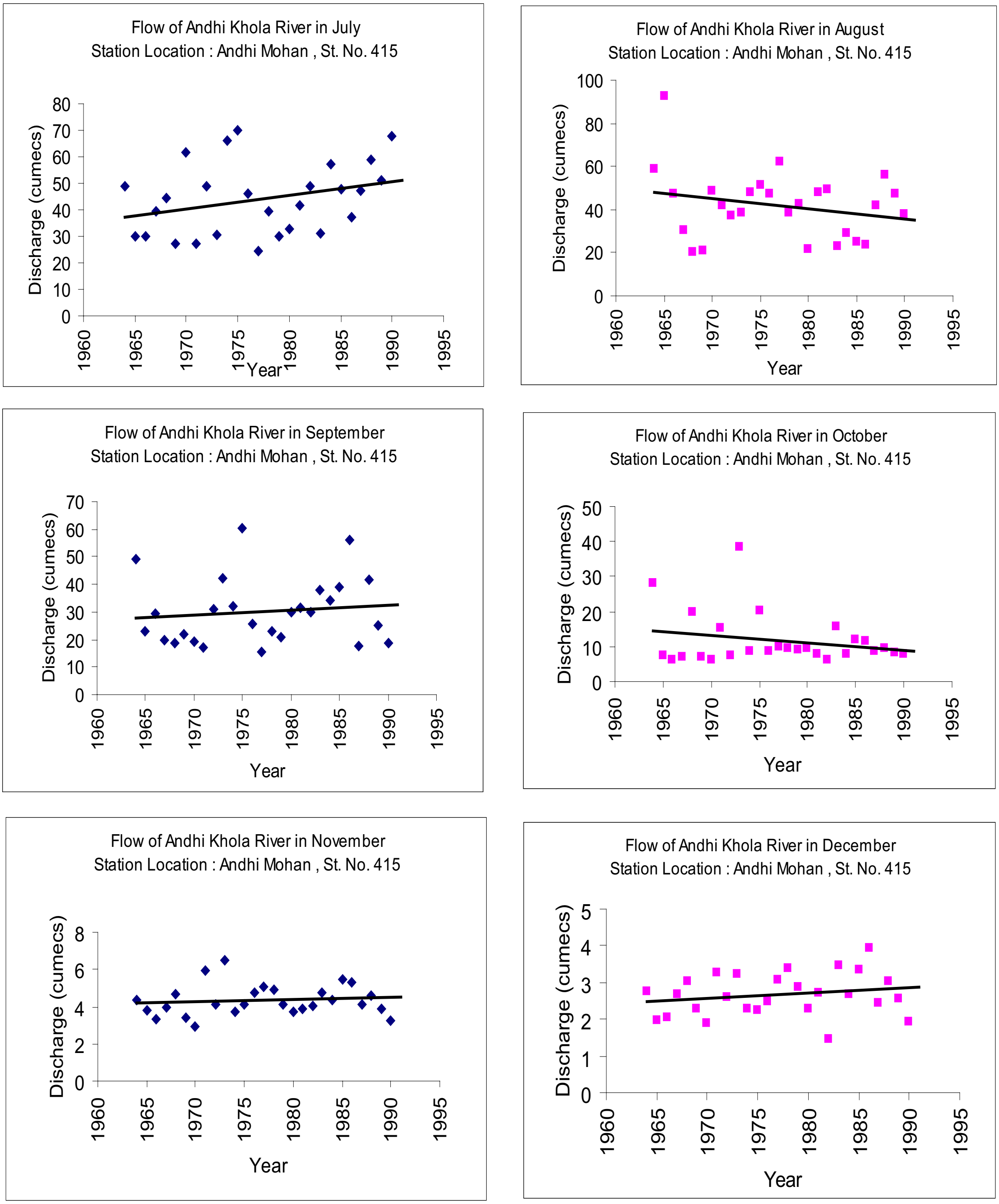


Figure 17: Monthly Trend of flow observed in the Andhi Khola at Andhi Mohan Station 415 (July-Dec.)

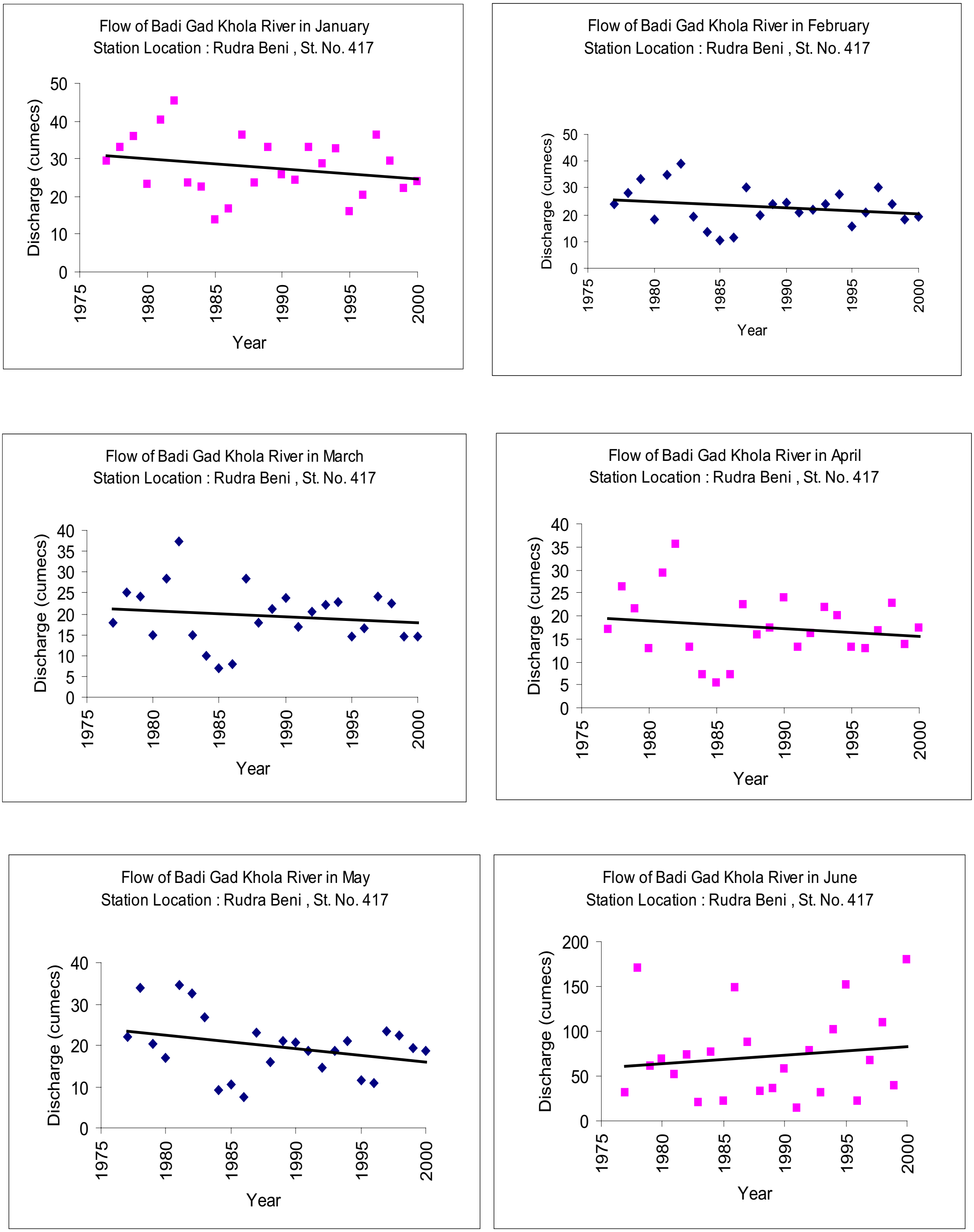


Figure 18: Trend of flow observed in the Badi Gad Khola at Rudra Beni Station 417 (Jan.-June)

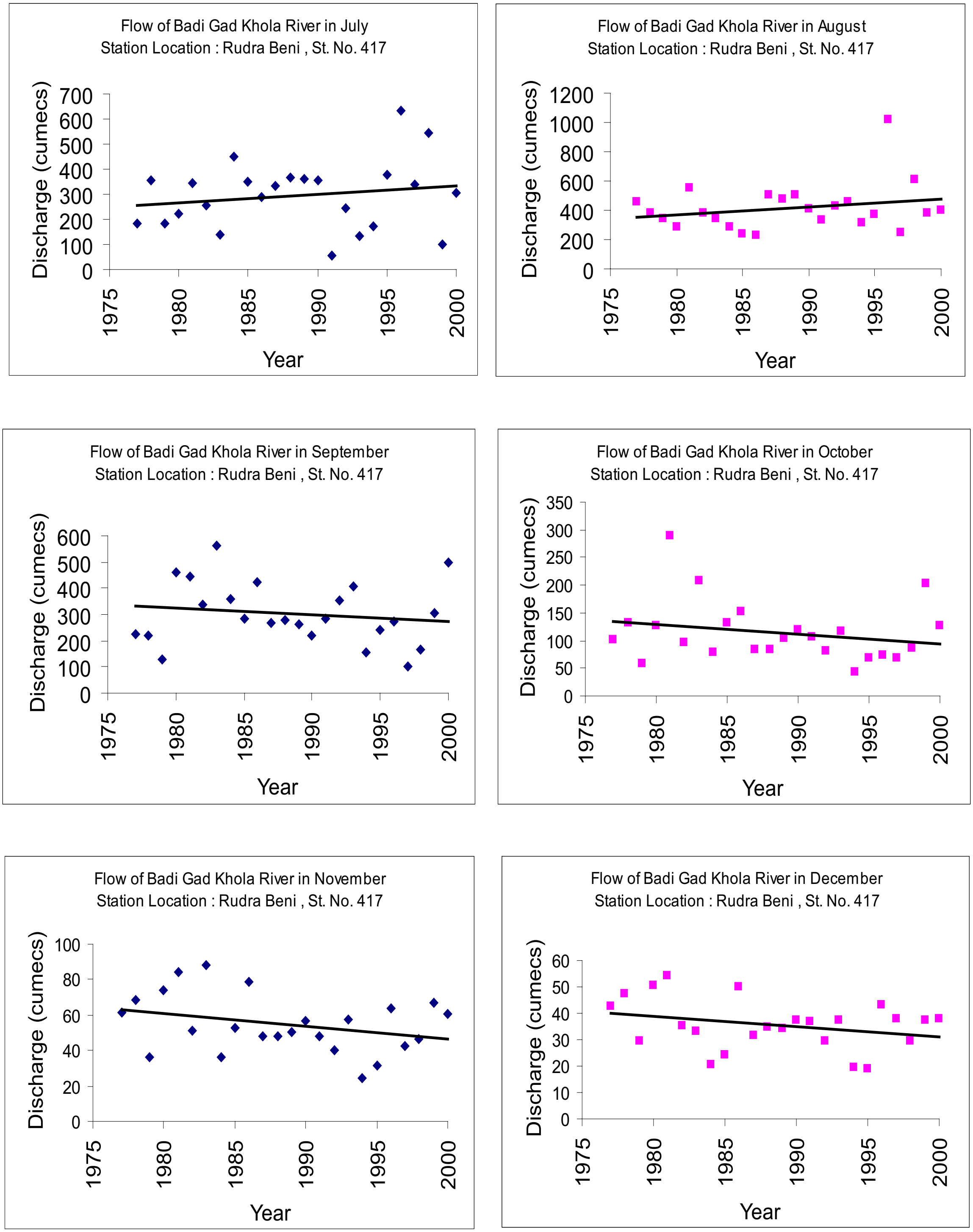


Figure 19: Monthly trend of flow observed in the Badi Gad Khola at Rudra Beni Station 417 (July-Dec.)

Although there are apparent trends in the stream flow volumes, the overall change in the mean stream flow is not very noticeable in most of the basins. But, their impacts on the month-wise distribution are clear. This would obviously affect the water availability in the river temporally. The early shift of the hydrographs seems to be clear in snowfed river basins like the Kali Gandaki (Figure 20) as also in the rivers originating in the midlands like the Bagmati (Figure 21). The shifting of the hydrograph also has an impact on the normal water withdrawal pattern of the river.

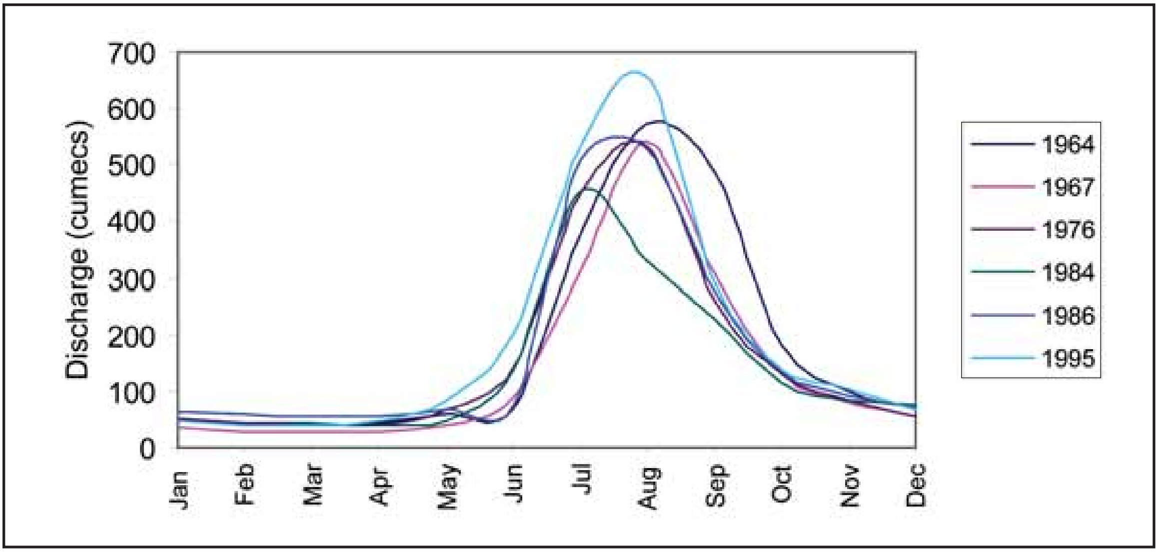


Figure 20: Shifting hydrograph in the Kali Gandaki River

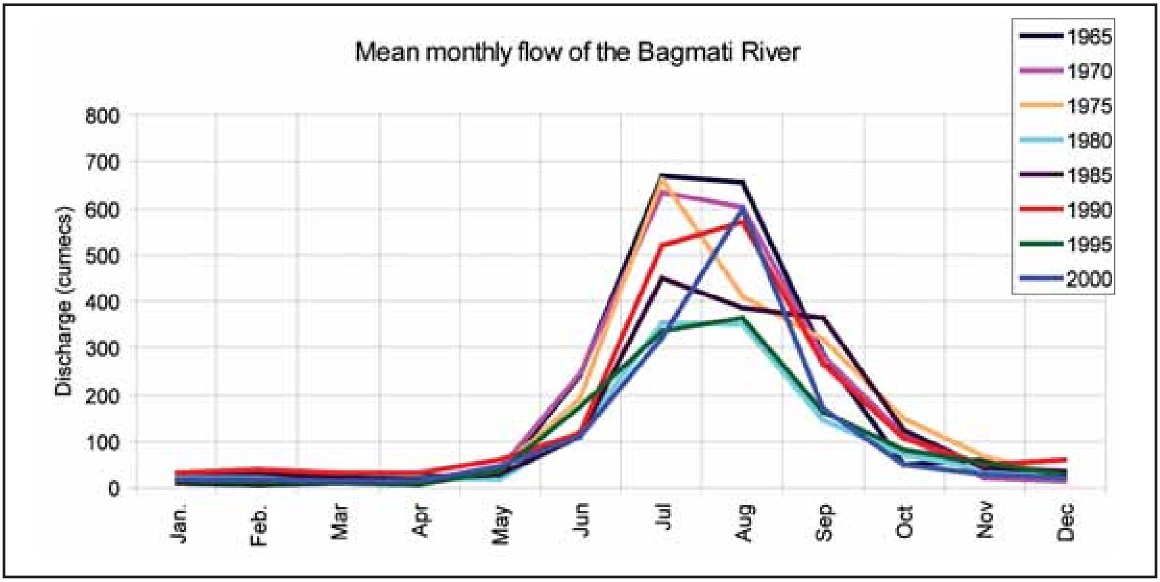


Figure 21: Shifting hydrograph in the Bagmati River

5.3. Impacts on Flood and Drought

As explained in the previous paragraphs, while the change is noticeable in the monthly flows, it is less evident in the case of annual flows. However, this change becomes more perceptible in the daily flows. Therefore, as a result of the change in the climate, most river systems face severe floods and droughts.

A flood event is considered as the flow that exceeds μ+σ at daily discharge; where μ is the mean and σ is the standard deviation. The total flooded days and the maximum duration of a single flood are important parameters of flood events. Figures 22 & 23 show the daily discharge of the Bagmati River in the monsoon period and the threshold line (μ+σ).

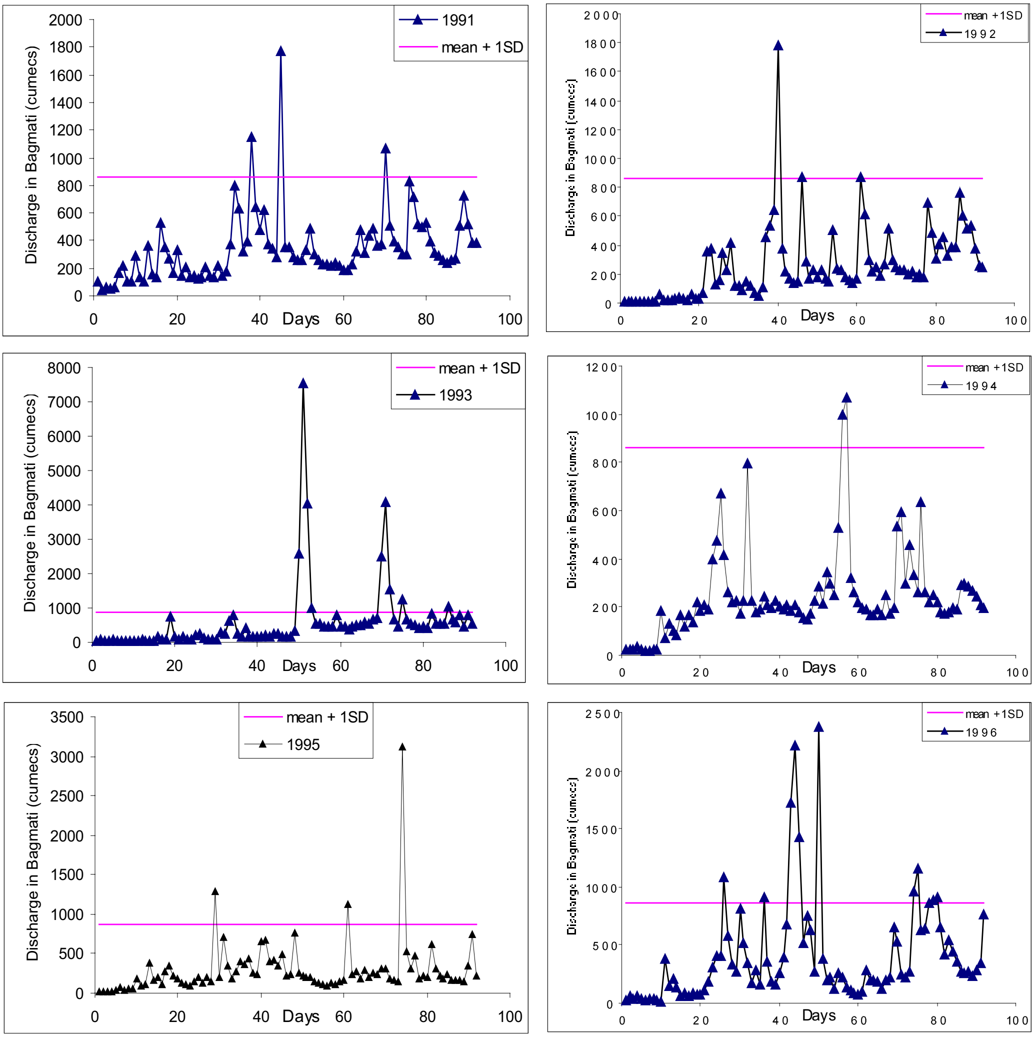


Figure 22: Daily discharge and the threshold line (μ+σ) of the Bagmati River for the floods between 1991-1996 (Shrestha KL. et al., 2003)

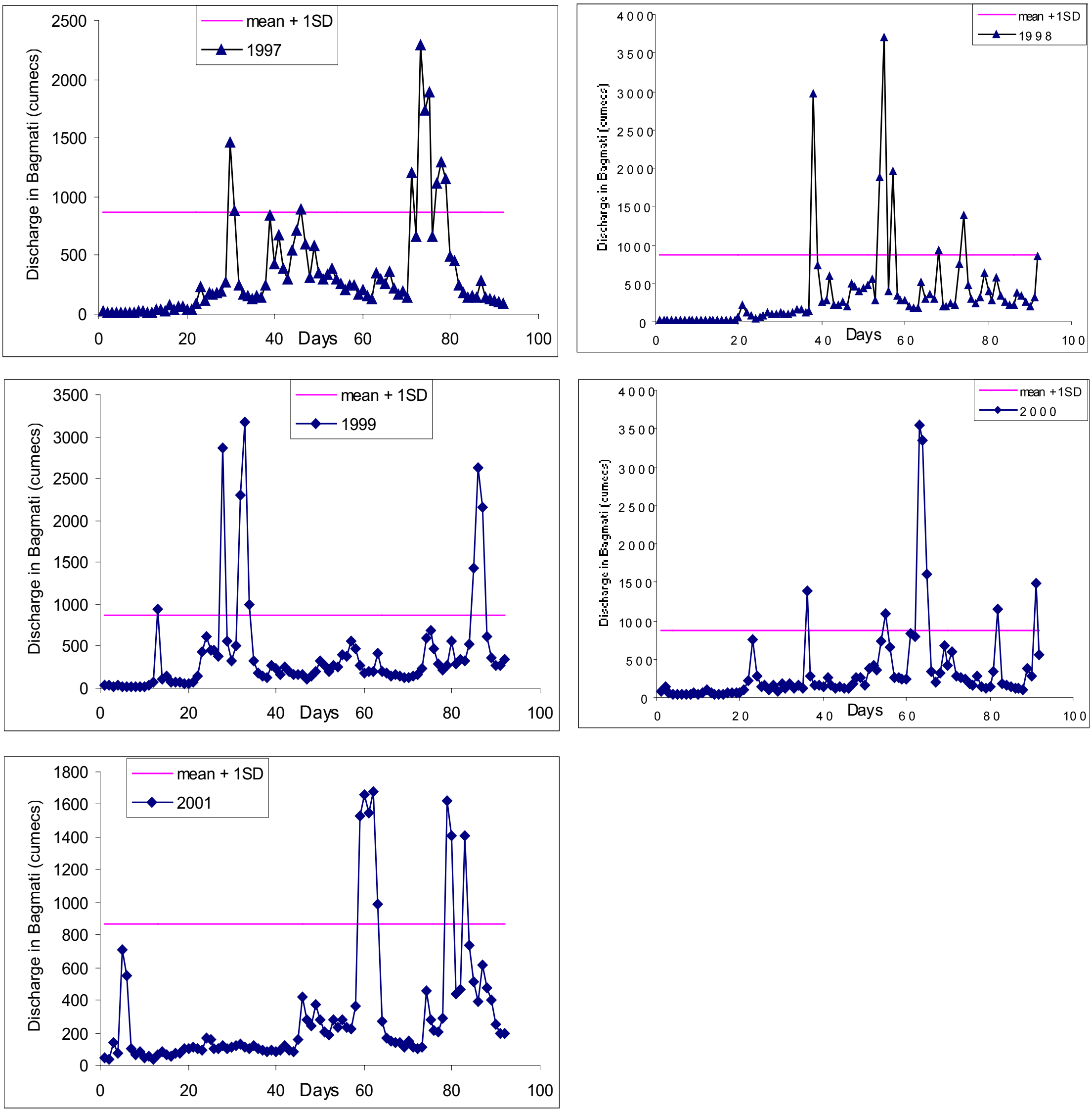


Figure 23: Daily discharge and the threshold line (μ+σ) of the Bagmati River for the floods between 1997-2001

Table 8 shows the number of flood events and the number of days they remain. Figure 24 shows the scenarios of the flood events in the Bagmati River. It can be seen that the numbers of flood events are increasing and the effect of a single flood is also increasing to more days.

Year	Nos. of consecutive flood event days						Total flooded days
	Flood 1	Flood 2	Flood 3	Flood 4	Flood 5	Flood 6	
1991	1	1	1				3
1992	1						1
1993	4	3					7
1994	2						2
1995	1	1	1				3
1996	1	1	3	1	2	2	10
1997	2	1	3	3			9
1998	1	2	1	1	1		6
1999	1	1	3	3			8
2000	1	1	3	1	1		7
2001	5	2	1				8

Table 8*:* Number of flood events and numbers of days they remain (Shrestha K.L. et al., 2003)

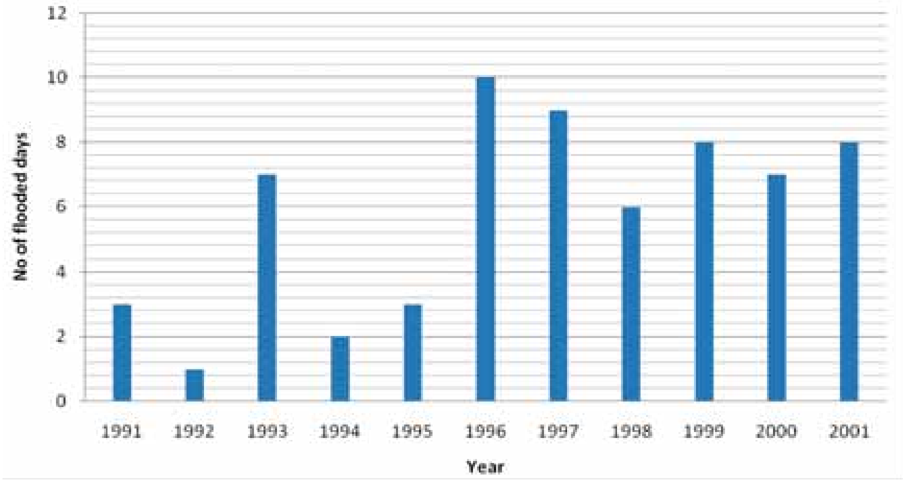


Figure 24: Trend of flood days with the flood discharge exceeding the threshold line (μ+σ) of the Bagmati River (Shrestha et al., 2003)

Droughts

The analysis of the precipitation records of the past revealed a decreasing trend in the number of rainy days. Conversely, the days with more intense precipitation were increasing, i.e. more precipitation occurred in fewer days. This changing precipitation pattern indicated that the drought period was becoming longer; however, there was no definite trend in the annual precipitation amount.

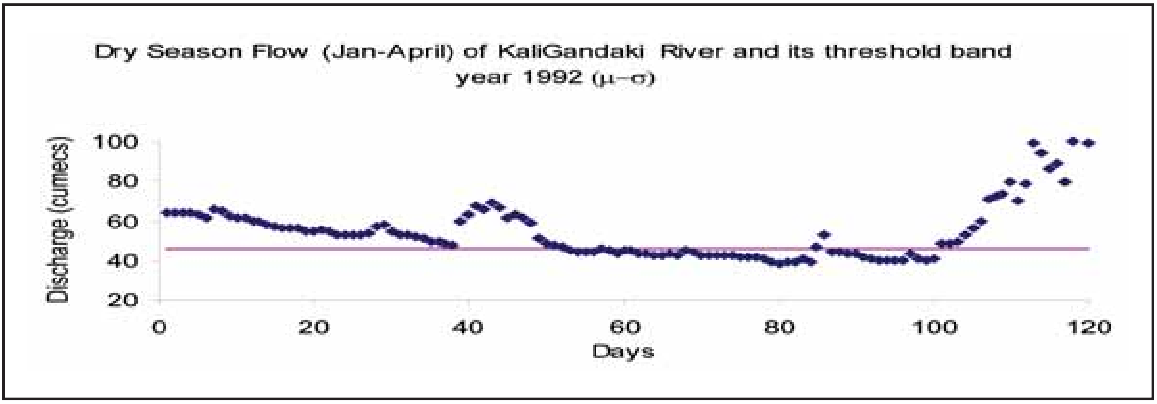


Figure 25: Typical plot of a drought period (below μ−σ) observed in the flow of the Kali Gandaki River (Shakya NM. 2004)

Impacts on Snow and Glaciers

Several studies conducted since the 1960s show that the glaciers have been retreating since the departure of the Little Ice Age of the mid-nineteenth century (Yamada, et al., 1992). Recent observations too have shown that many Himalayan glaciers are retreating rapidly as a result of global warming. Yamada et al. (1992) suggest that compared to the earlier decades, the retreating rate of glaciers in Eastern Nepal has increased in the 1980s. This accelerated retreat closely confirms to the obvious rise in Nepal since the late 1970s (Shrestha AB. et al., 1999). Compared to the 1970s, the glacier retreat has accelerated in recent times (Bajracharya S. et al., 2007). In fact, global warming is accelerating the melting of Himalayan glaciers at a rate faster than the global average; the snow line is rising; and some glaciers could potentially disappear or stabilize at a much reduced mass (Sharma E. et al., 2009).

Using the imageries of Satellite Pour Observation de la Terre (SPOT), Seko et al. (1998) studied the changing pattern of the Khumbu Glacier and detected its gradual shrinking. Likewise, by comparing the 1978 survey and the ground survey of 1995, Kadota et al. (2000) found that the surface had lowered by about ten meters. In the same glacier, Naito et al. (2000) predicted the formation and enlargement of a depression in the lower ablation area about five kilometers upstream of the terminus. This study was based on the model coupling the mass balance and the flow dynamics of the debris-covered glaciers. Moreover, another study revealed the retreat of seven glaciers in the Khumbu region at a range of thirty to sixty meters during the period from the 1970s to 1989 (WWF Nepal, 2005). Similarly, glacier retreat in Mt. Sagarmatha Everest has been confirmed by the Sino-American expedition of 1997. It was found that between 1966 and 1998; the Rongbuk Glacier retreated by two hundred seventy meters.

The Landsat imageries (Figure 26) acquired in 1975 (October 15), 1992 (September 22) and 2000 (October 30) are relatively comparable with regard to the assessing of the changes in the snow, ice cover, glaciers and lakes (WWF Nepal, 2009).

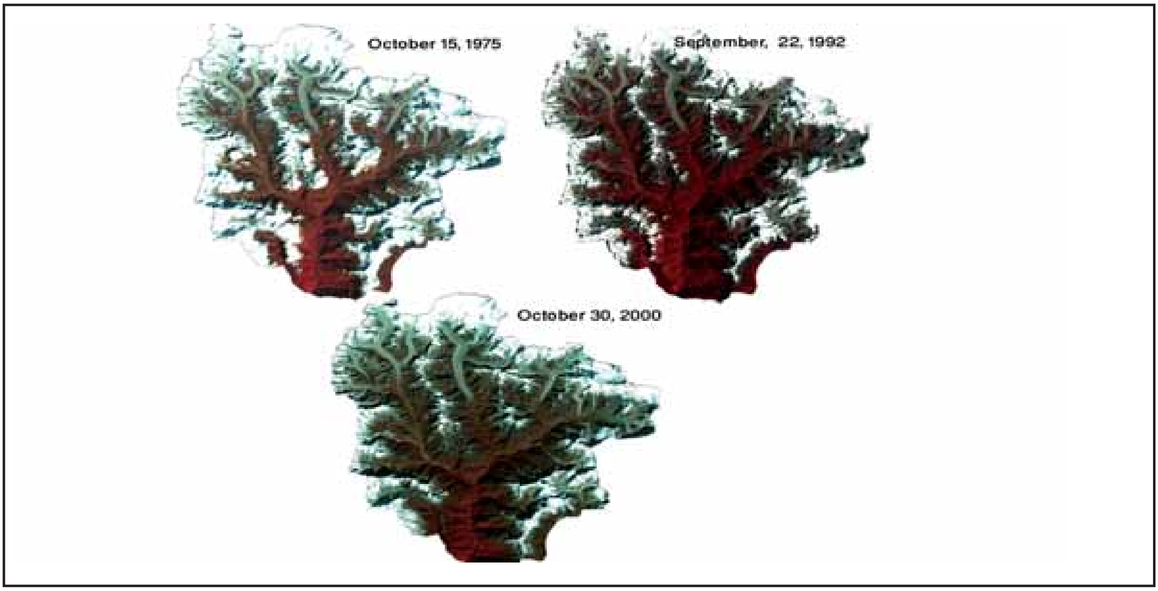


Figure 26: Temporal comparison of the Landsat imageries of the Dudh Koshi Basin

These imageries clearly show there has been a decline in the snow and ice coverage during the last twenty-five years. They clearly show that the snow line too has receded. Between 1975 and 2000, there has been a decrease of nearly 40 % (29208.3 ha) in the snow- and ice-covered areas (Table 9). If this trend continues, it will have a very severe impact on the hydrological regime. Conversely, there has been an increase in both the exposed rock areas and the areas under debris-covered glacier (17.8 %). Compared to the changes from 1975 to 1992, there was lesser change in the snow cover between 1992 and 2000. Similarly, comparing the imageries of 1975 and 2000, there appears the formation of various glaciers lakes; mainly, the supra glacier lakes in the Ngozompa and Imja Glaciers. Between 1975 and 2000, the area occupied by the major lakes (detectable by the visual interpretation of he imageries) has also increased by 8.3%.

Similarly, the time series plot of temperature (Figure 27) and precipitation (Figure 28) recorded at the Syangboche Station and observed by the DHM indicates that there is an apparent trend showing an increase in the minimum temperature and the maximum precipitation, thus creating a conducive environment for snowmelt.

AX010 - one of the widely studied glaciers in the Eastern Nepal Himalaya - retreated by 160 m between 1978- 99 and has shrunk by 26% in 21 years, from 0.57 km^2 in 1978 to 0.42 km^2 in 1999 (Fujuta K. et al., 2001a). It retreated by 30 m yr^{-1} in 1978-1989, and by 51 m yr^{-1} in 1998-1999 (Ibid). Similarly, the Rikha Sambha Glacier in the Western Nepal Himalaya retreated by 300m during 1974-1999(Fujuta K. et al., 2001b). Moreover, the rate of glacier retreat was found to be increasing in recent years. In fact, all of the observed glaciers in the Himalaya have been retreating during recent decades (Ageta Y. et al., 2001) at a rate higher than any other mountain glaciers in the world (Nakawo M. et al., 1997).

Many rivers draining the glaciated regions, particularly in the Hindu Kush-Himalaya, are sustained by glacier melt during the summer. In the beginning, higher temperatures generate increased glacier melt. As these glaciers retreat due to global warming, river flows are increased in the short-term. But, the contribution of glacier melt will gradually decrease over the next few decades (IPCC, 2007; Sharma E. et al., 2009). The formation of large lakes is occurring as glaciers retreat from the prominent Little Ice Age (LIA) moraines in several steep mountain ranges, including the Himalaya (IPCC, 2007).The thawing of buried ice also threatens to destabilise the LIA moraines. These lakes thus have a high potential for GLOFs (IPCC, 2007).

Land cover	Year 1975	Year 2000	Change area	% Change
Snow and Ice	73588.3	44380.0	-29208.3	-39.7
Debris glacier	9958.1	11731.5	1773.4	17.8
Lake	394.3	427.0	32.6	8.3
Others	57273.5	84675.8	27402.2	47.8
Total	141214.3	141214.3		

Table 9: Snow and ice cover condition and their change (in ha) in the Dudh Koshi Basin (Source: WWF Nepal)

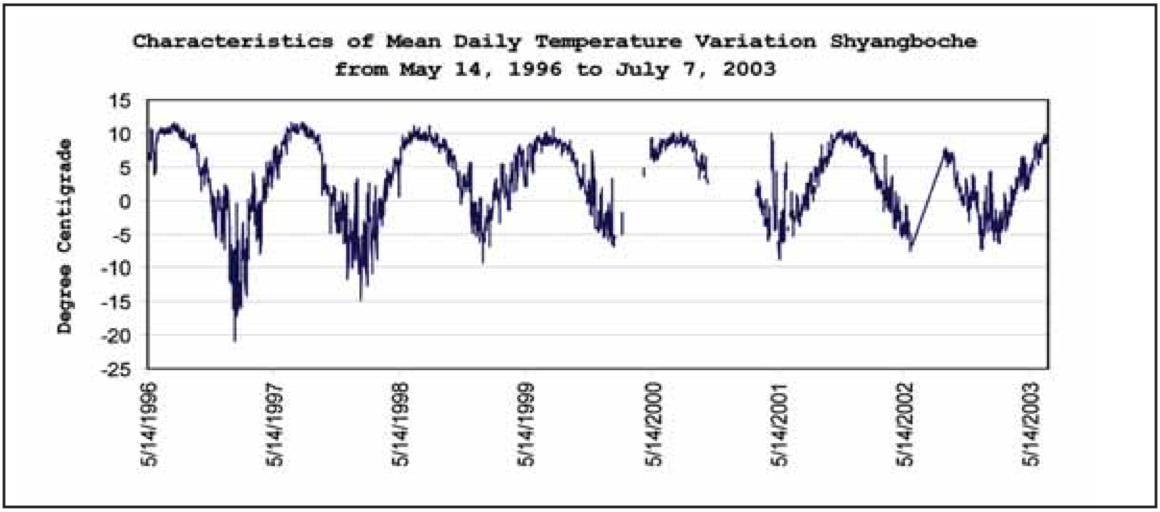


Figure 27: Temporal variation of mean daily temperature observed at Syangboche

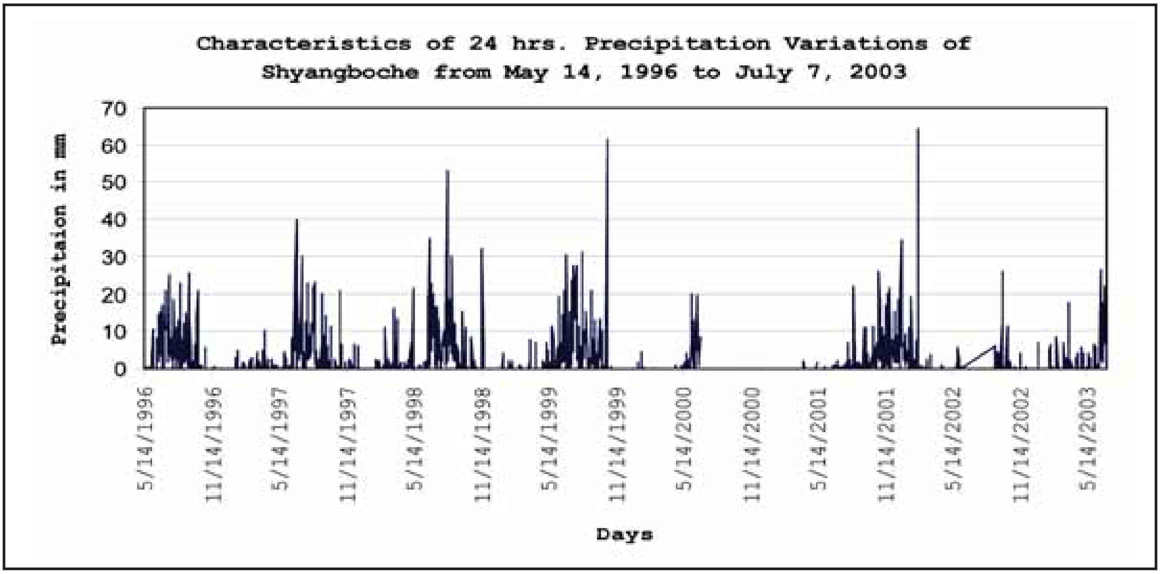


Figure 28: Temporal variation of precipitation observed at Syangboche

Increasing temperatures reduce the proportion of snow to rain. This in turn causes the reduction in glacier accumulation and a decrease in the surface albedo which result in increased glacier ablation (Ageta Y. et al., 2001). Therefore, reduced snowfall simultaneously decreases accumulation and increases ablation which ultimately results in accelerated glacier retreat. The melting of snow and glaciers amplifies the warming effect by providing additional feedback (Meehl GA. 1994). This may result in the rapid retreat of glaciers, the creation of new glacier lakes and the expansion of the existing glacier lakes. Glacier lakes are developed in the space once occupied by their mother glaciers and are generally supported by loose moraine dams (Mool P. et al., 2001). Many glacier lakes have been formed during the second half of the last century in the Himalaya (Yamada T. 1998). The supporting moraine dam can collapse due to the increased hydrostatic pressure of greater water depths in the glacier lakes. This may cause an immediate release of a large volume of the lake water and a devastating flood known as glacier lake outburst flood (Yamada T. 1998; IPCC, 1998).

A number of scenarios that may arise due to a continued glacier retreat in the Himalaya - relating to the future changes in the stream flow - have been envisaged. One of these, proposed jointly by the Worldwild Fund for Nature (WWF Nepal, 2006) and the Intergovernmental Panel on Climate Change (IPCC, 2007), has suggested that by 2100, the air temperature will increase by 3 0C as a result of climate change. For the glaciers in the Nepal Himalaya, the primary effect of this temperature increase will be to cause a rise in the equilibrium line altitude (ELA) - the separation of ablation and accumulation areas on a glacier. As implied in the WWF-IPCC scenario, the final spatial distribution of glacier ice - after a century of continuous negative net budgets - depends, to some extent, on the initial starting conditions.

As suggested by the WWF/IPCC scenario, if there is no change in the current precipitation amounts or patterns during this century, it is estimated that the estimated 5300 km2 of glacierized area in the Nepal Himalaya may decrease by approximately 50%-60% during 2000-2100. This will come about due to the upward migration of the ELA into the accumulation zone, from an altitude of approximately 5400 m in 2000 to approximately 5850m in 2100. However, even in 2100, the peaks and cirques above approximately 4000 m will continue to hold ice. The loss of surface area will all occur below the transient ELA. This will involve the ice already below the ELA in 2000 as well as the ice transferred by the flow from the accumulation zone in accordance with the laws of ice dynamics.

A temperature increase will not only have an impact on the annual glacier mass balance but will also change the precipitation pattern. With warmer temperatures, even without any change in the total annual precipitation, more of it will occur in a liquid form (i.e. rainfall) instead of a solid form (i.e. snowfall). Rainfall, unlike snowfall, will not be stored. Instead, it will immediately be drained out from the basin. This will result in more floods downstream during the monsoon. The impact of a temperature rise could easily be visible in the sensitivity analysis through the snow to rain ratio, the glacier mass balance rate or the life of the glacier ice reserve. For example, a study has shown that with a warming of 4ºC, the snow to rain ratio in the Langtang would decrease from 1.6 to 0.5; the life of the ice reserves would decrease from 110 to 25 years; and the glacier mass balance would decrease from -1.114 to -4.850 m.w.e.yr-1 (Chaulagain NP. 2004).

There have been more than 13 GLOF events in Nepal since 1964 till 1998. In fact, some glacier lakes have collapsed more than twice during the last 40 years. The Zhangzangbo Glacier Lake (at the headwaters of the Sun Koshi River) has collapsed twice in 1964 and

1981 and the Ayaco Glacier Lake (at the head of the Arun River) thrice in 1968, 1969 and 1970. The Zhangzangbo GLOF (July 11, 1981) caused substantial damage to the diversion weir of the Sun Koshi Hydropower Plant, the Friendship Bridge at the Nepal-China border, two other bridges and extensive road sections of the Arniko Highway. These amounted to a total loss of more than US $ 3 million. Similarly, the Dig Tsho GLOF (August 4,1985) in the Khumbu region (Eastern Nepal) destroyed - over a distance of 42 km - the Namche small hydroelectric plant with an estimated loss of US $ 1.5 million, 14 bridges, 30 houses, trails, farmlands and the properties of many families, including three human lives. On September 3, 1998, the Tam Pokhari GLOF in the Dudh Koshi Basin (Eastern Nepal) destroyed 6 bridges and farmlands (with an estimated loss of US $ 2 million), including two human lives (Mool P. et al., 2001a, p.135).

The conclusion of the studies of past GLOF events and applied risk reduction measures in Nepal is that the threats of potential damage by GLOFs in Nepal are imminent and the costs of the possible risk reduction measures are extremely high for a country like Nepal. GLOFs are the new threats arising from climate change in the Nepal Himalaya. Both the empirical and model studies suggest that in the future, due to the effects of climate change, there will be more new glacier lakes and the existing glacier lakes will grow rapidly in the Nepal Himalaya. The historical records of the past GLOFs suggest that the frequency of these events appears to be increasing. The damage magnitude depends not only on the characteristics of the lake like volume, surface area and the rate of water-release but also on the natural features of the river channel and the status of infrastructure and habitation (YamadaT. 1998, p.14).

5.4. Impact on Agriculture and Livelihoods

The agricultural water demand, particularly for irrigation, is considerably more sensitive to climate change and becomes more critical for crop production as the conditions become hotter and drier (Frederick and Gleick, 1999; IPCC, 2001b). Climate variability directly affects agricultural production as agriculture is one of the most vulnerable sectors to the risks and impacts of global climate change and water shortages (Ziervogel G. et al., 2006; Frederick and Gleick, 1999; Becker and Bugmann, 2001). Any further decreases in water resources, especially during the non-monsoon seasons, would adversely affect agricultural production. The lack of water, in association with higher temperatures, is the most limiting factor for agricultural productivity (Ziervogel G. et al., 2006).

Small changes in the climate can induce large changes in agricultural risk in the mountains. This is because the risk levels often increase exponentially with altitude. Out of the total cultivable area of 2.64 million hectares in Nepal, only 1.14 million hectares (i.e. 43%) had modern irrigation facilities at the end of 2004 (MoF, 2005). Subsistence farmers, non-irrigated lands and the crops already at their maximum temperature tolerance are the most vulnerable to climate change (IPCC, 2001b). Marginal farm households account for approximately 28% of Nepal's total population. Subsistence agriculture contributes 43% to the total household income in Nepal (FAO, 2004) and the majority of the population is subsistence farmers. An optimum range of temperature for rice cultivation in Nepal is 22-30ºC (MoPE, 2004). Most of the Southern Terai plains of Nepal, where most of the rice is cultivated, already have an annual average temperature near or above 30ºC (Yogacharya K.S. 1998). Any further increase in temperature beyond this optimum range will adversely affect the production of rice in these areas. The situation will be compounded by the increased water stress brought about by the increasing trend in temperature rise.

The warming climate will increase evaporation and precipitation which will lead to an intensification of water. The changes in precipitation and evaporation have a direct effect on crop water use. Longer drought periods, considered to be one of the expected impacts of climate change, increase water stress on crops. This could reduce both the growing period and the productivity of the crop. The impacts of droughts are not limited to crop water use. They also affect the irrigation water supply due to changes in the river flow regimes. Warmer temperature increases both the water holding capacity of the atmosphere and the evaporative demand, i.e. potential evapotranspiration. Despite an increase in potential evapotranspiration, the reduction in soil moisture storage decreases the rate of actual evapotranspiration.

A study carried out by the MoPE (2004) showed that temperature rise had negative effects on maize and gave a decrease in yield with an increase in temperature. The average potential yield increased by about 12% in Nepal considering the effect of double CO2 (580ppm) without an increase in ambient temperature. A double CO2 condition, with a 4º C rise in temperature and 20% increase in precipitation, showed 12% to 35% decrease in the potential maize yield in the hilly and Terai region of Nepal (MoPE, 2004).

The Indian subcontinent has a strong linkage between monsoon activity and agricultural productivity. However, since the last decade (1990-2000), particularly Nepal and the Indo-Gangetic plains of India, immediately south of the mountain region, have experienced a significant reduction in the yield of winter crops due to severe sky overcast. Compared to the average of the preceding 10 years, the yield reduction in 1997/98 ranged from 11% to 38% (MoPE, 2004).

Agriculture is extremely vulnerable to climate change in Nepal. The overall agriculture production system is still traditional, unmanaged and too slow to adopt new technology. The changes in water availability during the monsoon, pre-monsoon and the post-monsoon season have a direct impact on Nepali agriculture. Rice production is already decreasing with a decrease in the monsoon flow.

The irrigation intensity of the system too has been considerably reduced due to the decrease in the dependable flow at the headworks of irrigation systems in Nepal like the Kamala, the Bagmati and the Khageri. This has resulted in less production of crops posing a big question regarding the sustainability of the system.

Chaulagain N.P. (2006) carried out an analysis on the decrease in rice production due to temperature rise. It was calculated by hypothetically reducing the equivalent land area of increased irrigation water demand (i.e., 1 m^3 of increased water demand = 1/15000 ha of rice field* 2.67 metric tonnes/ha of rice yield = 0.18 kg of rice). A 5ºC rise in temperature would cause a decrease in the average per capita supply from 2440 kcal/day to 2264 kcal/day. Because of the large disparity in consumption patterns among the population, such a decrease would have different effects on the various income groups.

5.5. Impact on Hydropower

Nepal is pulling out, in some ways, on her own to meet the electricity demand. To cope with and plan for the increasing demand of electricity, the Nepal Electricity Authority (NEA), during the preparation of its corporate development plan for the period 2004/05-2008/09, brought out a load forecast upto the year 2019-20. It is based on the power consumption data of the fiscal year 2004/05. The total energy requirement in Nepal is projected to go up by an average of about 8% per annum over the forecast period - from 2299.9 GWh in the fiscal year 2003/04 to 7894 GWh in the fiscal year 2019/20. The electricity demand forecast is expected to be met by generating energy from various existing as well as new projects.

The generation expansion plan and their subsequent implementation for meeting the forecast are based on the assumption that the existing projects will be producing the same amount of power in the long run as well. To enhance the existing electricity supply capacity of its grid, the NEA has put forward a few hydro projects for implementation in the near future. With these projects implemented by the year 2012/13, an addition of about 626 MW to its grid will be possible. It is hoped that with these additions, the future demand will be met. However, even after the planning of new projects and their timely implementation, the power demand might not be satisfied.

There might be significant declines in the dependability of dry season flows in certain rivers. This is critical for both water and energy supply. For example, Shakya NM. (2002) found that by 2030, the long-term 92.3% dependable flow of the Bagmati River, currently at 21.1 m^3/sec, is projected to decline to 9.86 m^3/sec. With the doubling in the amount of CO2, it will further be reduced to 7.43 m^3/sec. On the other hand, the intra-annual variability of the stream flow is also projected to increase significantly. The current range of the Bagmati is 316.26 m^3/sec (from a low of 21.1 m^3/sec to a high 337.36 m^3/sec). With climate change, this variability in flow will increase to 810.37 m^3/sec (from a low of 7.43 m^3/sec to a high of 817.8 m^3/sec). These scenarios will render it more complex for hydropower planners and engineers to maintain electricity generation throughout the year.

Most of the installed capacity of a hydropower plant is designed based on the 65% dependable flow. It is done so by using the past records of few years. The most severe projections for Nepal show that the runoff could be reduced by 14%. The projection, using the climate model for dependable flow, is even more severe. However, with only 1-2% of its potential currently developed, it will be quite some time before the opportunities to expand hydropower energy are constrained by climate change. This, of course, does not mean that the existing facilities might not be seriously affected by a combination of variable flows, flooding risks, sediment load in the river due to intense rainfall and GLOF events.

Both the annual and the monthly hydrographs of Nepal are generally influenced by the monsoon rains. There is a significant contribution of melt-water during the dry season (March-May). It contributes about 13% to the total annual runoff and about 32% to the dry season runoff (Table 10). Most of Nepal's hydropower plants are run-of-the-river types which are designed for dry season flows (i.e., minimum flows).

Months	Rainwater, km^3	Melt-water , km^3			Total, km^3	Melt-water,%
		Snow	Glacier	Subtotal		
January	3.40	0.75	0.05	0.8	4.20	19.0
February	2.83	0.78	0.05	0.83	3.66	22.7
March	2.49	1.07	0.08	1.15	3.64	31.6
April	2.56	1.12	0.10	1.22	3.78	32.3
May	3.67	1.36	0.39	1.75	5.42	32.3
June	10.88	2.18	1.17	3.35	14.23	23.5
July	32.63	2.60	1.62	4.22	36.85	11.5
August	37.96	3.69	1.55	5.24	43.20	12.1
September	31.05	2.31	0.93	3.24	34.29	9.4
October	13.20	0.65	0.11	0.76	13.96	5.4
November	6.18	0.35	0.02	0.37	6.55	5.6
December	4.18	0.16	0.01	0.17	4.35	3.9
Annual	153.00	17.00	6.08	23.08	176.08	13.1

Table 10: Estimated all-Nepal monthly runoff components (Chaulagain NP. 2006)

In general, the hydropower potential is a function of the average flow and the vertical drop available for the particular flow. The change in hydropower potential is directly proportional to the change in the total water availability, if all the other factors like technological advancement, site alterations etc. were assumed constant. Chaulagain NP. (2006) found that, initially, with the increased glacier-melt brought about by the increase in temperature, the hydropower potential increases. However, further warming will add no more to the hydropower potential but will instead reduce it at the latter stages due to the reduced glacier-ice reserves. The glaciers in the Nepal Himalaya have been retreating so fast in recent decades that there will be a 6% decrease in hydropower potential at the end of this century even without any further warming. Assuming that 32% of the total hydropower potential in Nepal will be sourced from snowmelt and the rest from rainwater, the theoretical hydropower potential of Nepal will rise with a warming of 0.06ºC/year by 5.7% by the year 2030. But, by the end of this century, it will decrease by 28% (Chaulagain NP. 2006).

The sediment-induced wear of the hydraulic machinery has been one of the major issues in the operation and maintenance of the RoR hydropower plants in Nepal. The high sediment concentration, combined with a high percentage of quartz content in the water, causes damage to the hydraulic machinery. Such damage leads to economic losses. The costs involved include the increase in costs of operation and maintenance, generation losses due to down time and losses due to the reduction in the turbine efficiency. Many hydropower plants built on sediment-loaded rivers have faced serious problems of sediment-induced wear during the first few years of operation. Based on the experience from some of the Indian hydropower plants, Naidu BSK. (1997) reported that the annual operation and maintenance costs of sediment-affected power plants could be as high as 5 % of the capital costs against 1.5 % in normal cases.

The 12 MW Jhimruk Hydropower Plant in Nepal may be taken as an example. The sediment study conducted in this power plant indicated that for about 15 % of the monsoon, the sediment concentration exceeds 4,000 PPM. The average content of quartz in the sediment is found to be above 60 % (Basnyat S. 1999). The high content of quartz and feldspar, which are harder than the turbine base material, is the main reason for the excessive sediment induced wear in the hydraulic machinery operating in this power plant. The photographs presented in Figure 29 illustrate the extent of sediment-induced wear in the turbines of the Jhimruk Hydropower Plant in Nepal and the Naptha Jhakri Hydropower Plant in India after operating during a single monsoon.

Figure 29: Sediment Induced wear of Hydro-turbine (Bishwakarma MB. 2008)

In Nepal, 90% of the debris volume is transported by approximately 20% of rainfall. Landslides are the main source of sediment loads of the river systems in Nepal.

Sediment transport in the Himalaya is a natural phenomenon. It cannot be completely controlled. It can be managed. Figure 30 shows a schematic view of a hydropower system. Sediment management can be done by planning a 3R strategy. This involves the reducing of sediment production from the catchment, the designing and operating of the headworks to remove the excessive amount of sediment and finally, the designing and operating of the turbines with the aim of resisting the sediment that passes through them. However, it is not easy to apply this strategy until we know how much should be handled in these three steps.

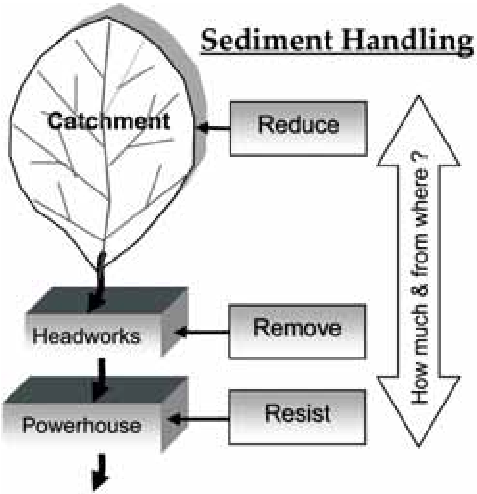


Figure 30: 3R approach in sediment handling (Bishwakarma MB. 2008)

For example, Figure 31 illustrates the relationship between rainfall intensity, cumulative rainfall and slope failure. Sediment discharge is correlated to 30-minutes intensity of rainfall (I30) and the average intensity of rainfall (Iavg). It was found that sediment concentration as high as 24,400 PPM passed through the turbines of the Jhimruk hydropower plant in a single event on July 31, 1996. The cost of its damage was estimated to be about ten times higher than the generated revenue. This example reveals that it is not always economical to operate a power plant without understanding the economic value of the water utilized for power generation. It demonstrates the need for establishing a concentration cut-off limit for a power plant in order to prevent costs climbing higher than the benefits. There is a level at each high head RoR hydropower plant where the costs of continued generation are higher than the benefits due to the excessive sediment-induced wear and the resultant maintenance costs. As a result of climate change, the consequences will be even more severe due to more extreme flood events with increased sediment concentration. In order to establish a limit for concentration cut-off, the measurement and analysis of sediments and the corresponding effects on generations need to be carried out (Figure 32).

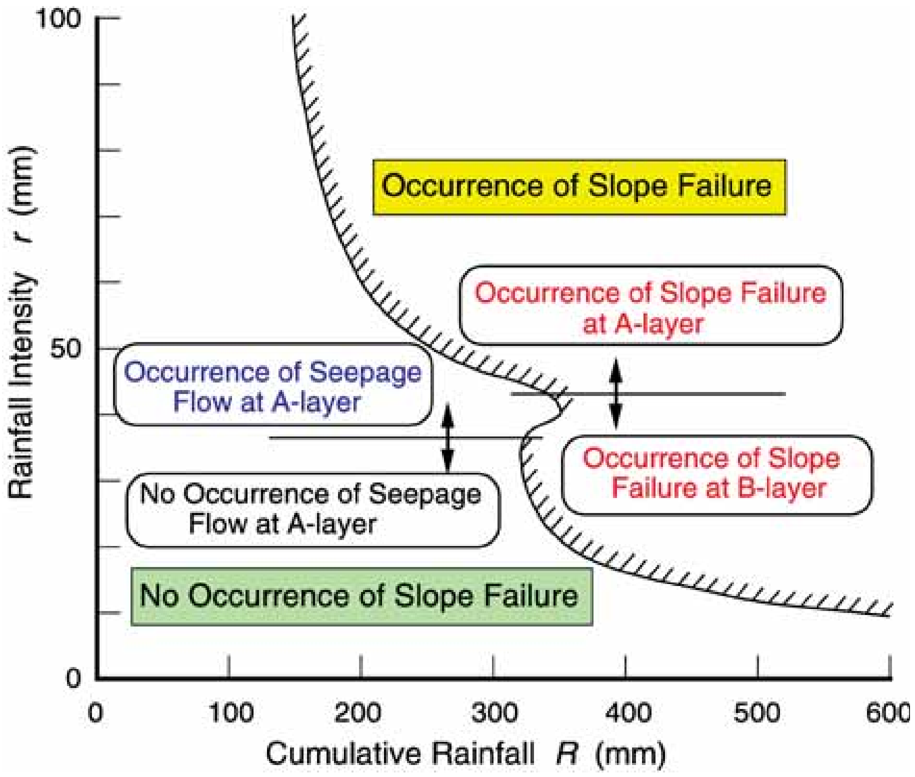


Figure 31: Domain of Shear failure

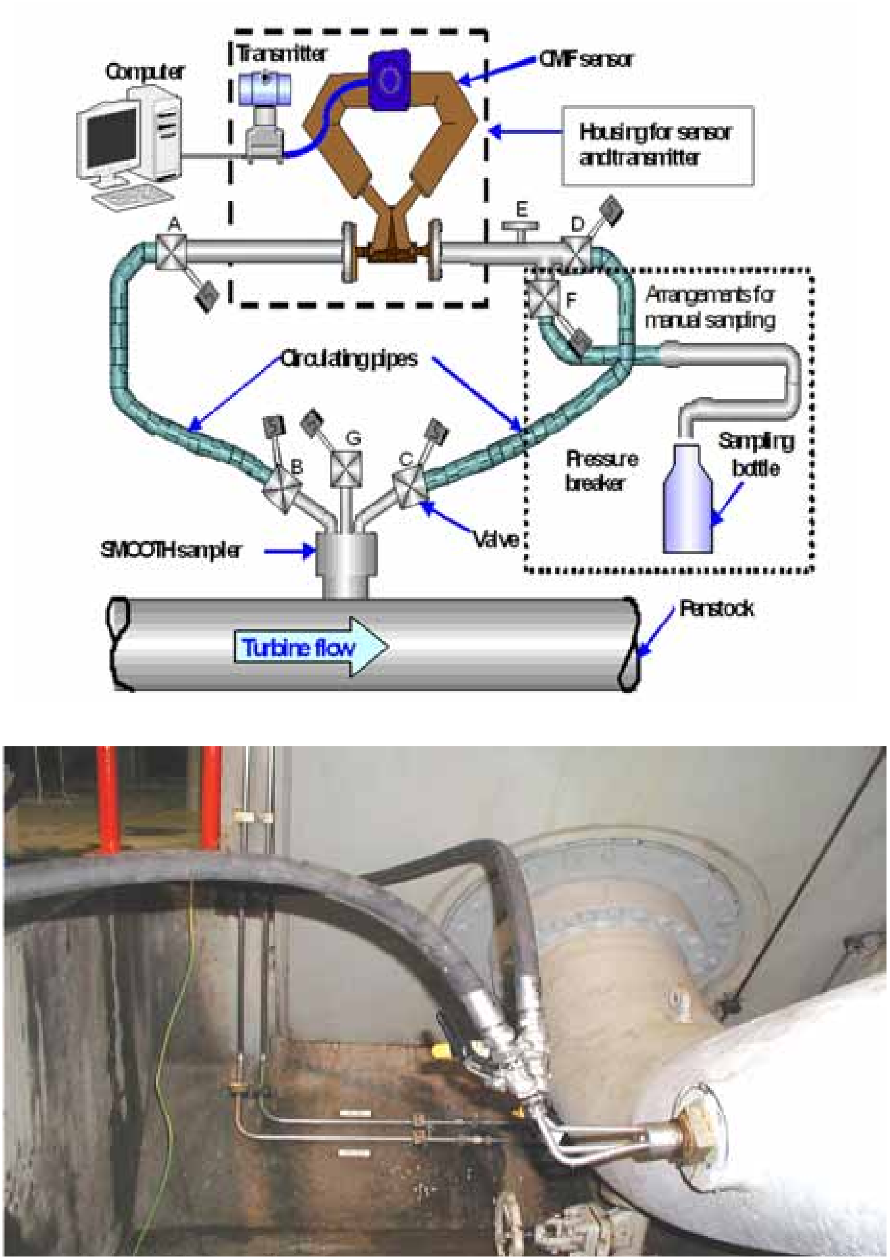


Figure 32: Installation of Smooth Sampler (Bishwakarma MB. 2008)

With the intense rainfall projected for the monsoon season, sedimentation is one of the factors that may shorten the operating life of even a storage hydropower plant. Figure 33 shows the economic losses incurred by such sedimentation in the reservoir of the Kulekhani Hydropower Plant.

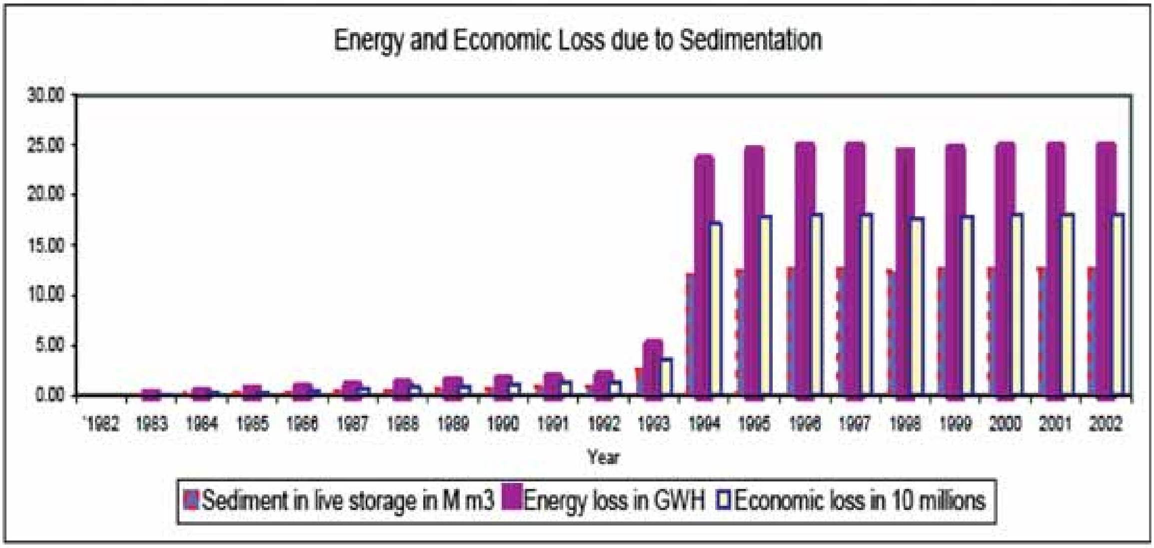


Figure 33: Energy and economic loss due to sedimentation in the reservoir of the Kulekhani Hydropower Plant (Sangroula DP. 2005)

Hydropower plants are constructed to meet the energy demand within a country and export the surplus. Normally, a project agreement is agreed upon to develop a project.Then, a power purchase agreement (PPA) or a power trade agreement (PTA) is signed prior to the implementation. It can be specified as follows:

- As operated regime (applicable for existing power plants only),
- Peak hours production regime,
- Maximum generation regime; and
- Maximum benefit regime.

Generally, the above listed operation regimes are equally applicable for any power plant. The maximum generation regime refers to a mode of operation where there is no power sales restriction and no shutdowns due to high sediment concentration. On the other hand, the maximum benefit regime demands a flexible power sales agreement and the power plant operation is guided by the pre-defined sediment concentration cut-off limit. Figure 34 illustrates the manner in which a maximum benefit regime operates with respect to different levels of sediment concentration in the turbine flow. In this example, production is plotted for a power plant having an installed capacity of 50 MW and the cut-off limit for sediment concentration is set at 2,000 PPM. It is assumed that the power plant should be shut down when the concentration exceeds the pre-set limit.

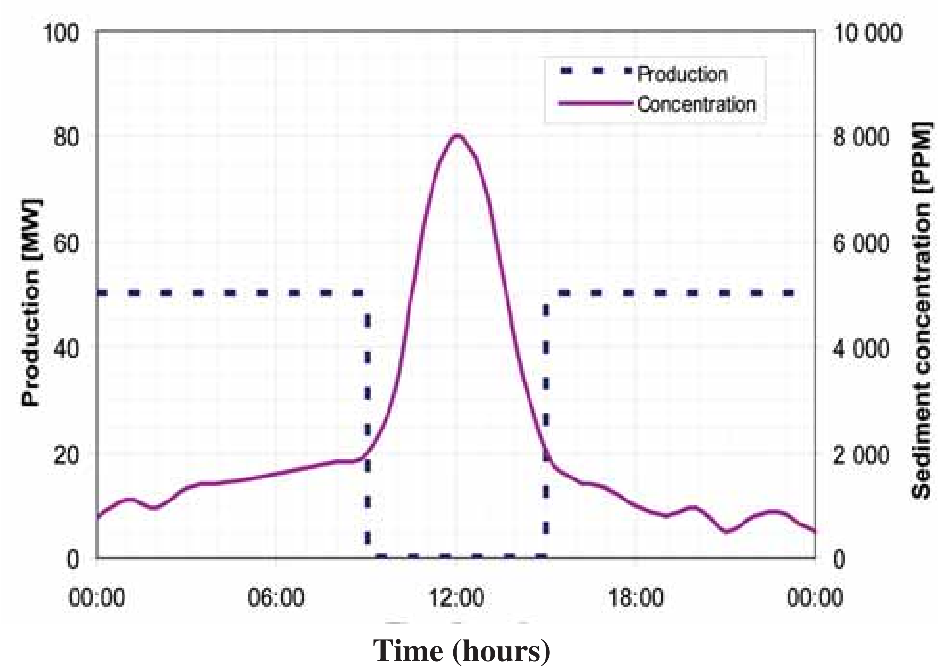


Figure 34: Maximum Benefit Regime of a RoR project (Bishwakarma MB. 2008)

5.6. Perceptions of the People on the Livelihood Systems in the High Himalaya

WWF Nepal (2008) conducted a field survey in different VDCs within the Sagarmatha National Park and its Buffer Zone in order to understand the people's perception about climate change, its impact on freshwater resources and GLOF hazards in the area. It comprised of checklists, key person interviews and focused group discussions. It also explored the ways in which people's livelihood are/shall be affected by these changes. The vulnerable components of both the community and livelihood system were identified and analyzed.

The impact of climate change was perceived by the people on agriculture, livestock and freshwater availability. The following responses were obtained from the group discussions regarding the perceived impact of climate change in their livelihood:

Impact on agriculture

- Winter snowfall is the main source of moisture supply and irrigation for agriculture during the cropping season. Less amount of snowfall in winter will affect the crops. Heavy snowfall during winter is always preferred because of the prolonged supply of moisture to the crops during the summer. However, it may also lead to the casualty of lives and livestock.
- Late snowfall or snowfall during spring affects the cropping schedule. Recently, such changes in the seasonal pattern have inhibited the farmers to sow crops like potato in prime time. This has resulted in the emergence of some pests and diseases that affect both the plant and its harvesting.
- Forward shift in the cropping schedule is likely to have a negative impact on tourism in the area. The late harvest would encroach upon the tourist season (mid-September to December) which is a crucial source of cash income in the area.
- Rapid melting of snow and as a result, of snow ice would cause huge amounts of debris and sediment delivery which may destroy their agricultural lands, forests and pastures.
- The present trend of warming will perhaps favour agriculture in the long run by providing scope for the cultivation of crops adapted to warmer conditions.

Impact on livestock

- Decline in snowfall in the winter is likely to reduce the availability of pastures in the area during summer. This in turn is likely to result in downsized livestock numbers and may reduce production. It has to be reckoned that alpine pasture-based livestock rearing is still an integral component of the livelihood system in the area.
- There is a repercussion of pasture decline in crop cultivation. The decrease in grazing livestock will lead to the reduction of manure supply for the farms as well as the grazing areas. This in turn will inhibit the recovery of both the crop fertility and the pastures which ultimately is likely to hamper the regenerative capacity of the production system.
- Livestock has, in the past, played a key role in the transportation of goods across the trans-Himalaya. Even today, it forms a crucial part of the trekking industry. *Jokpio* (a cattle-yak cross breed), an animal used for transportation, is either the main or subsidiary source of income for many households. But, it is likely to decrease in numbers if enough pastures are not available.

Impact on fresh water availability

Freshwater is life supporting system. People perceive that the decline in the snow mass in the Sagarmatha region is likely to reduce the availability of freshwater.

Freshwater - apart from a source of moisture supply to agro-pastoralism - is used for drinking, cooking, washing, wine making, hotels and lodges, irrigation, running of *ghatta (*hydropowered local grain mills), *maaney* (prayer wheel) and micro hydropower including peltriset, and for religious purpose like pilgrimages.

6. Conclusion and Recommendations

Although climate change is a global phenomenon, both its trends and impacts may be different on a local scale. The local hydrology of every river in the world is likely to be affected by climate change in some ways. It affects different aspects of the local hydrology of a river such as the timing of water availability, quantity and quality. These changes in the river hydrology will induce risks to water resources facilities in the form of flooding, landslides, sedimentation from more intense precipitation events (particularly during the monsoon) and greater unreliability of dry season flows.

The latter poses potentially serious risks to water and energy supplies in the lean season. For the long-term planning and management of water resources, the future changes in the pattern of land use, water demand and water availability should be analyzed well in advance. It entails understanding the manner in which a water resources system responds to changing trends and variability, the manner in which it is affected by these conditions today and how it might respond if these conditions undergo change. The assessment of climate change helps build resilience against its possible impacts through enhanced institutional flexibility and the consideration of climate-related risks in the planning process.

The impact of climate change on water resources depends not only on changes in the volume, timing, quality of the stream flow and the recharge but also on system characteristics, changing pressures on the system, the manner in which the management of the system evolves and the adaptation measures implemented for climate change. Non-climate changes may have a greater impact on water resources than climate change in the managed basins. But, the unmanaged systems are likely to be most vulnerable to climate change. Climate change challenges the existing water resources management practices by adding an additional uncertainty. With the increasing variability in climate which is sure to grow even more extreme in the future, developing countries are particularly vulnerable to extreme weather events.

Hydrologically, water resources in Nepal can be categorized into three different groups: (a) dry pre-monsoon season (March–May) with almost no rain (b) rainy monsoon season (June–September) (c) post-monsoon season (October–February) with little rain. Most of the agricultural water demands are by rice in the monsoon, wheat in the post-monsoon and by maize in the pre-monsoon season. The following are the features of river flow in Nepal:

- Less monsoonal rains across the high mountains and more monsoonal rains along the southern hills,
- The frequency and duration of small floods affected the most. Although their magnitude is decreasing, floods in the river seem to be more frequent and of longer duration,
- Snowfed rivers have an early shifting and non-snowfed rivers have a late shifting of the hydrograph,
- Rapid retarding of glaciers. The formations of glacier and supra-glacier lakes pose great threats of GLOF to infrastructure downstream,
- Rapid decrease of snow cover will firstly diminish the storage capacity of natural reservoirs and then the dry season flow in the rivers; and
- Climate change will produce excess water in the wet season but little flow in the dry season. This will pose a challenge to the planners and managers concerned.

The poor are more vulnerable to climate extremes as well as gradual changes in the climate as they have less production, less reserves, fewer alternatives and lower adaptive capacity. About 31% of the population in Nepal is below the poverty line and 95% of them live in rural areas. Moreover, as much as 70% of the rural population is poor and the local food production sometimes just covers three months of the annual household needs. The impacts of climate change on the livelihoods of the poorest of the poor in Nepal would therefore be substantial.

Climate change and climate risks in general are neglected in the country's development policy. For example, power sector plans do not recognize the risks faced by the hydropower plants due to the variability in the runoff, floods (including GLOFs) and sedimentation. Similarly, climate risks have not been mentioned in the irrigation sector plan. However, some of the activities like the mitigation of floods, mitigation in the erosion of cultivated areas and water harvesting to provide year-round water supply for irrigation would fit well into an adaptation strategy for Nepali agriculture. Likewise, the introduction of a non-conventional irrigation project in the Department of Irrigation also fits well into adaptation measures.

Through this project, the department has already implemented sprinkler and drip irrigation systems in 1800 ha of land and has set a target for 10,000 ha. The introduction of the poor and the marginalized to this non-conventional system would strengthen their coping capacity. This would be brought about with the introduction of diversified crops and less dependency on rain-fed conventional agriculture and the diminishing supply from surface irrigation, both of which are highly vulnerable to climate change.

For sites lacking perennial or adequate water sources, simple solutions like rainwater harvesting schemes and solar pumps are also included in the government policy. However, the real climate-related risks (what is “adequate” and how do you deal with a water source that is usually perennial but dries up during a period of drought) are not discussed.

Activities like the establishment of a national disaster preparedness and management agency, the creation of village-level early warning systems for floods, landslides etc., building decentralized emergency response capacity, enforcing design standards for buildings and infrastructure that take into account site-specific risks, investing in better weather and earthquake prediction systems, the monitoring of lakes and preparation of siphon materials(specifically for GLOFs) are some of the coping measures adopted by the Nepal government in the context of climate change.

One adaptive response to GLOF risks is to promote the development of smaller hydropower plants. This would spread the risk in the event of a catastrophic flood and negate the scenario of damage to a huge plant with significant sunk costs. The development of micro and small hydro is already in line with Nepal’s development priorities and is being encouraged by both the government and the donors. In other words, climate change might be one supplementary motive to promote a strategy that is already being implemented for reasons of economic development.

The introduction of multiple units in power plants, alternative sources of energy supply and a better demand-side management are some of the noted approaches adopted by Nepal in coping with the adverse effects of climate change in the hydropower sector. In addition, the initiation of Optimum Sediment exclusion (OSE) research in the Jhimruk and Khimti hydropower plants is a step forward in the adaptation/mitigation measure in the context of climate change. It will help improve the performance of both the existing as well as the planned hydropower projects. This will lead to the maximizing of benefits from such projects and the minimization of both the construction costs and the overall environmental effects caused by the construction of new projects to meet an equivalent energy demand.

In Nepal, Kulekhani is the only storage project generating electricity. By the efficient utilization of RoR hydropower plants, equivalent water can be saved in the Kulekhani reservoir to generate power at peak hours. This can help in reducing the duration of the present load-shedding hours. As an example, a 2% increase in the performance of the existing power plants in Nepal can generate the equivalent of 11 MW of extra power which is equivalent to 264,000 units per day. In the dry season, an equivalent amount of energy in the form of water can be stored in the Kulekhani reservoir and supplied during the peak hours.

River-linking projects like the Sunkoshi-Kamala diversion, the Bheri-Babai diversions and several multipurpose high dam projects are envisaged in the government policy. They act as additional intentions in place to cope with the stream flow fluctuations as a result of the current seasonal as well as climate variability.

There is an urgent need for the optimal use of available water in order to increase agricultural production. Out of the total cultivable area of 2.64 million hectares in Nepal, only 1.14 million hectares (i.e. 43%) had modern irrigation facilities at the end of 2004 (MoF, 2005). The productivity of the irrigated areas in Nepal is one of the lowest in South Asia. There are a number of factors behind this low level of production but reliable irrigation is the key issue. Reliability is a relative term and a scheme supposed to be reliable twenty years ago may not be rated so now. To meet the demand for more food, the productivity has to be increased. At the same time, high valued crops have to be grown in order to make agriculture profitable. These demand for a more flexible and assured water supply that is difficult with the present level of infrastructure and the design and operation concepts.

7. Way Forward, Future Activities and WECS's Role

In order to address the issues related to climate change, it is necessary to strengthen and expand the hydrological and meteorological observation networks for short-, medium- and long -term data collection. The station network should be as per the WMO standard. Likewise, there should be adequate instruments for data analysis and communication as per the need of the project and a proper mechanism to assure the long-term sustainability of the observation network. The network should be equipped with robust tools, effective methods and capable human resources for data collection, compilation, processing, monitoring, evaluation and upgrading.

Similarly, the establishment of a strong water resources database including snow and glacier information is required. Integrated river basin study, pilot river basin study demonstration projects, development of suitable climate models, establishment of a model test laboratory, redefinition of the water structure design criteria and identification of vulnerable areas and climate friendly technologies, development of adaptive measures and proper implementation, researches on water resources for the application of the 3R (reduce, reuse and recycle) principle as well as studies on addressing the climate change impacts on landslides, debris flows, floods and droughts are also necessary to cope with climate change. The creation of mass awareness, formation of climate change sectoral policies on matters related to water resources, stringent judicial enforcement, reliable information of the Himalayan snowfields and glaciers, capable human resources development and the creation of opportunities for higher studies are some of the other necessities that are to be planned and carried out in a proper and effective manner.

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